FOLIAR PIGMENTS, NITROGEN, AND CARBON ISOTOPE RESPONSES TO PRESCRIBED BURNING IN A CORSICAN PINE FOREST

Magali Cannac,[1] Vanina Pasqualini, Paul-Antoine Santoni, and Lila Ferrat

University of Corsica, Faculty of Sciences, UMR 6134 CNRS, B.P. 52, 20250 Corte, France

ABSTRACT

Fire is a major ecosystem disturbance and can be an important ecological hazard in forests of Corsica (France). Management strategies have recently included a range of mitigation treatments, including prescribed burning, to restore fire to the ecosystem, recreate natural disturbance dynamics, and reduce fuel load and fire hazard. Very few studies have characterized the responses of tree physiology to season of burning and time-since-fire. This study examined the effects of prescribed burning on the needles of Corsican pine (*Pinus nigra* ssp. *laricio* var. *corsicana*) using pigments, nitrogen (N), and carbon isotopes as indicators of a thermal stress. Our investigation was carried out in the Valdu Niellu Forest, a naturally regenerated stand, located in Corsica. The objective of this study was to determine the impact of season of burn (spring, fall) and time-since-fire (1 month to 1.5 years) on physiological compounds. Prescribed burns were conducted in April and October 2006. Needles were collected in March 2006 before the prescribed burns in order to provide a pre-treatment reference measurement, then samples were collected in May, July, and November 2006 and in June and October 2007. Pigments decreased during 3 months after the burning, with a greater decrease after spring burning. Foliar N contents increased until 1 year after prescribed burning. We suggest that this increase is due to N inputs to the soil, attributable to the falling of scorched needles. Foliar N can be used as a bioindicator of response of plants to environmental disturbance such as thermal stress. No variation in carbon isotopes was found. Prescribed burning, whether conducted in the spring or fall, had similar effects on the physiological parameters of Corsican pine, apart from pigments. The results appear to offer some flexibility in using prescribed burning in Corsican pine forest management.

Keywords: Corsica, Corsican pine, pine needle, *Pinus laricio*, prescribed fire, repetition, season.

Citation: Cannac, M., V. Pasqualini, P.-A. Santoni, and L. Ferrat. 2010. Foliar pigments, nitrogen, and carbon isotope responses to prescribed burning in a Corsican pine forest. Pages 114–118 *in* K.M. Robertson, K.E.M. Galley, and R.E. Masters (eds.). Proceedings of the 24th Tall Timbers Fire Ecology Conference: The Future of Prescribed Fire: Public Awareness, Health, and Safety. Tall Timbers Research Station, Tallahassee, Florida, USA.

INTRODUCTION

Every year, wildfires burn 700,000–1,000,000 ha of wildlands in the Mediterranean region. Most of these fires are a direct or indirect consequence of modifications in the intensity and type of land use that have progressively taken place since the mid-20th century (Vélez 2000). Forestry services use many mitigation treatments for scrub removal, such as prescribed burning (Fernandes and Rigolot 2007). Prescribed burns are implemented in an attempt to restore fire to the ecosystem, recreate natural disturbance dynamics, and reduce fuel load and fire risk (Weber and Taylor 1992). Prescribed burning is widely used in the United States (Carter and Foster 2004) and also in the Mediterranean region, including Portugal (Fernandes and Botelho 2004) and France (Rigolot 2000). Knowledge of physiological changes in pines (*Pinus* spp.) in response to fire is important for forest management and the use of prescribed burning.

The effects of prescribed burning or wildfire on the physiological functioning of different species have been examined in several studies. For example, Alonso et al. (2002) used pigment content to characterize heat damage to maritime pine (*Pinus pinaster*) stems and crowns and reported a short-term increase in pigment content.

Physiological responses have been followed through carbon isotope discrimination ($\delta^{13}C$), providing an integrated measure of plant response to changes in the environment, such as water availability (Damesin et al. 1997). $\delta^{13}C$ is used to express the relative abundance of the isotopes carbon-12 (^{12}C) and carbon-13 (^{13}C) in plants. These stable isotopes are present in carbon dioxide (CO_2) in ambient air. They are incorporated by photosynthetic CO_2 assimilation into plant organic matter, but the two isotopes do not appear in plants in the same proportions as in the air. After a fire, resprouting leaves in oak (*Quercus* sp.) have been shown to have lower $\delta^{13}C$ and higher photosynthesis (Fleck et al. 1996).

Nitrogen (N), the major constituent of proteins, nucleic acids, and chlorophyll (Salisbury and Ross 1978), is the most common limiting factor to forest productivity (Waring and Schlesinger 1985, Fisher and Binkley 2000). Prescribed burning with thinning seems to increase leaf N content between 2 and 6 years following fire (Feeney et al. 1998, Wallin et al. 2004). Sala et al. (2005) and Zausen et al. (2005) reported no long-term change for leaf $\delta^{13}C$ and N in ponderosa pine (*Pinus ponderosa*) following fire. Generally speaking, these physiological responses were linked with changes in soil parameters. Sala et al. (2005) showed that prescribed burning, conducted in fall or spring, had no effect on soil nitrogen content 8 years later. Hatten et al. (2008) reported the impact of varying season on soil chemistry in ponderosa pine forests. Very few studies have characterized the responses of plant physiology to season of burning, especially in conifer needles.

The aims of this study were to: 1) evaluate the effects of prescribed burning on the functioning physiology of

[1] Corresponding author (cannac@univ-corse.fr).

Corsican pine, *Pinus nigra* ssp. *laricio* (Poir.) Maire var. *corsicana* (Loud.) Hyl; and 2) determine which season, spring or fall, has the most positive or least negative effect on the physiology of Corsican pine.

MATERIALS AND METHODS

Study Site

The study site was located in Valdu Niellu Forest (lat 42°17′03″N, long 8°55′22″E) in the northwest of Corsica (France). The experiment was conducted on 2-ha naturally regenerated stands of young Corsican pine (Table 1). Age of trees ranged from 10 to 12 years. Height of trees varied from 10 to 14 m. Understory vegetation was mixed bramble (*Rubus* sp.) and fern (*Pteridium aquilinum*).

Three plots of 0.2 ha in area were selected to be similar in structure and composition. Three treatments were applied to assist in assessing the fire effects: spring burn, fall burn, and unburned control. A prescribed burn was conducted on the first plot in April 2006 (PB-Spring; ambient temperature: 18°C; fuel load: 540 g m^{-2}; Byram fireline intensity: 29 kW m^{-1}) and on the second plot in October 2006 (PB-Fall; ambient temperature: 20°C; fuel load: 1,080 g m^{-2}; Byram fireline intensity: 58 kW m^{-1}) by the Office National des Forêts. Fuel moisture content was about 11 and 36%, respectively. The rate of spread was the same for both plots, 0.03 m s^{-1}. The third plot was not burned (UnB). There was no wind during the prescribed burns and no tree mortality, and the crown scorch was about 15–20% in each plot.

Needle Sampling Protocol

One-year-old needles on six dominant trees at different dates were sampled. Needles were collected at 6 m above the ground. Needles were collected in March 2006, before the first prescribed burn treatment, in order to have an initial-state measurement. For each plot, samples were collected from the same trees in the same location in the crown in May, July, and November 2006, and June and October 2007. After sampling, the needle samples were placed in a cooler and kept cool during transportation to the laboratory.

Pigments

Chlorophylls *a* and *b* were extracted using the method of Hiscox and Israelstam (1979) with dimethyl sulfoxide (DMSO). Fresh needles (50–80 mg) were placed in a vial containing 5 mL DMSO and were frozen. Pigments were extracted at 60°C for 8 hours. Spectrophotometrical readings were made at 649.1 and 665.1 nm (Wellburn 1994).

Table 1. General characteristics of the Valdu Niellu Forest study site, Corsica.

Characteristic	Average ± SE
Elevation (m)	1,070
Slope (%)	5–10
Substrate	Granitic
Understory vegetation cover (%)	55 ± 5
Mean understory vegetation height (cm)	76 ± 8.2
Mean annual rainfall (mm)	1,090
Mean annual temperature (°C)	11.5
Needle length (cm)	9.85 ± 0.17

Nitrogen and Carbon Isotope

Needles were frozen (−26°C) and lyophilized (freeze-dryer FD 4-85, Heto, Langenselbold, Germany; 48 hours). Nitrogen and $\delta^{13}C$ were analyzed by the Centre National de la Recherche Scientifique-Service Central d'Analyse (CNRS-SCA; Vernaison, France). C and N were measured by dry combustion in an autoanalyzer Carbon–Nitrogen (CNRS-SCA) coupled with an isotope ratio mass spectrophotometer (Finningan δS). The $\delta^{13}C$ content is expressed in delta notation as $\delta^{13}C$ (‰) and the nitrogen concentrations in percent (%). The measure was referenced to bottled CO_2 calibrated by an isotopic reference substance supplied by the International Atomic Energy Agency.

Statistical Analysis

Analysis of variance (ANOVA) was used when the application conditions were satisfied, i.e., normal distribution of treatment group means as tested using the Shapiro–Wilk test and homogeneity of variance between means as tested using the Bartlett test. ANOVA was used to test for differences in chlorophyll *a* concentration, % total N, and $\delta^{13}C$ concentration in needles among spring-burned, fall-burned, and unburned plots. In each plot, there were six replicates (six dominant trees). Differences were considered significant at the $P < 0.05$ level. If differences among treatments were significant, the Tukey-HSD test was used to make multiple comparisons among treatment groups. Statgraphics for Windows software (Statpoint Technologies Inc., Warrenton, VA) was used for these various tests.

RESULTS

Pigments

Before prescribed burns, pigment content in needles of Corsican pine was similar for the different plots (chlorophylls *a* and *b*; ANOVA, $P > 0.05$; Figure 1). For both spring and fall burn treatments, chlorophyll *a* was lower 1 month following burning (ANOVA, $P < 0.05$). However, by 3 months following burning, there were no differences among treatments (ANOVA, $P > 0.05$).

Needle Nitrogen Content

Before prescribed burning, N contents in needles of Corsican pine were similar for the different plots ($P > 0.05$; Figure 2). The two prescribed burns did not affect the N contents of Corsican pine 1 and 3 months later (ANOVA, $P > 0.05$). The prescribed burns, conducted in spring and fall, resulted in an increase in N content 7 and 8 months later (ANOVA, $P < 0.05$). N contents returned to normal values on PB-Spring and PB-Fall after 1 year (ANOVA, $P > 0.05$).

Needle $\delta^{13}C$

Before burning, $\delta^{13}C$ contents in needles of Corsican pine were similar among plots ($P > 0.05$). The two prescribed

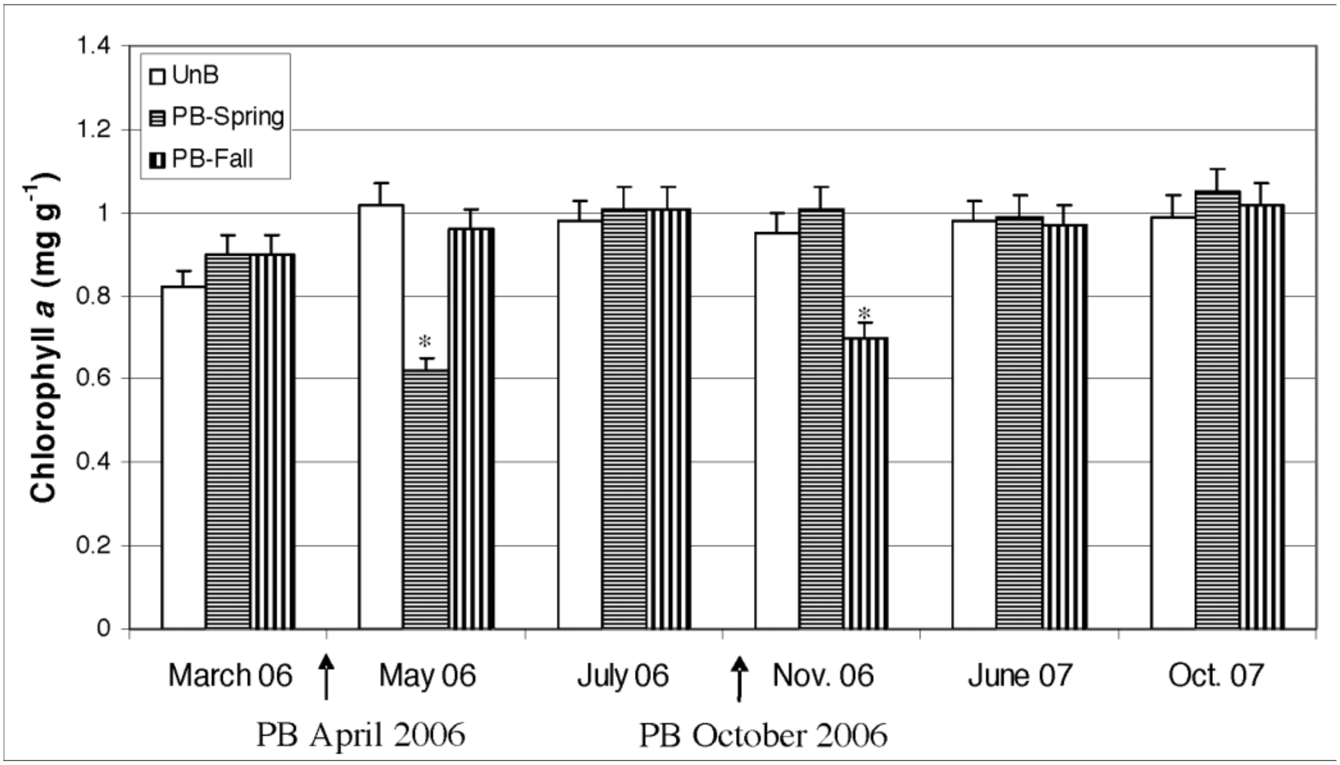

Figure 1. Chlorophyll *a* contents (mg g^{-1} dry weight ± SD) of Corsican pine needles at 6 m ($n = 6$; * significant difference between stations, ANOVA, $P < 0.05$) in Valdu Niellu Forest, Corsica. Prescribed burns (PB) were conducted in April (PB-Spring) and October (PB-Fall) 2006. The control plot was not burned (UnB).

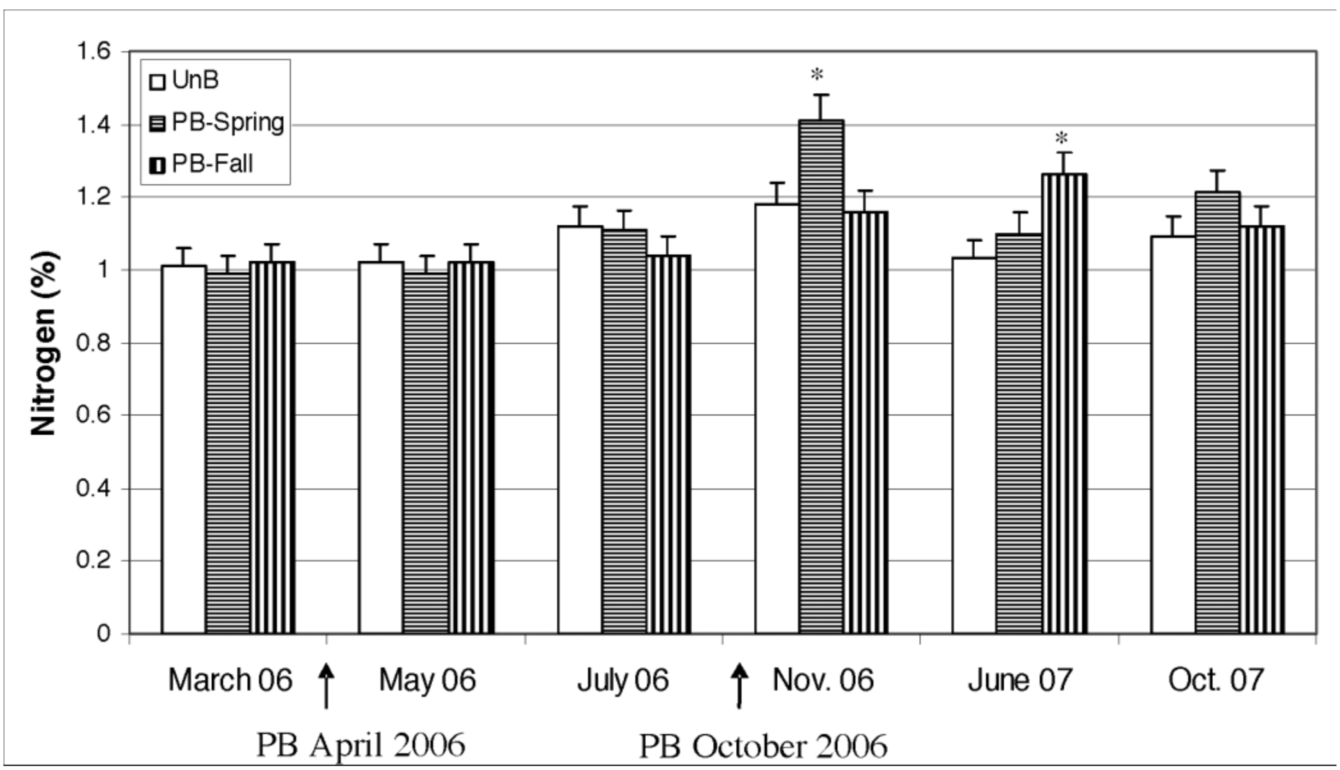

Figure 2. Nitrogen contents (% of dry weight ± SD) of Corsican pine needles at 6 m ($n = 6$; * significant difference between stations, ANOVA, $P < 0.05$) Valdu Niellu Forest, Corsica. Prescribed burns (PB) were conducted in April (PB-Spring) and October (PB-Fall) 2006. The control plot was not burned (UnB).

burns did not influence the $\delta^{13}C$ values of Corsican pine needles between 1 and 18 months ($P > 0.05$). The average $\delta^{13}C$ values in Corsican pine needles varied from −24.46 ± 0.78‰ (UnB, November 2006) to −26.82 ± 0.37‰ (PB-Fall, November 2007).

DISCUSSION

Impact of Prescribed Burns

The decrease in pine needle pigments within 1 month of burning is similar to that observed for other species in past studies. Trabaud and Méthy (1988) showed a photosynthetic decline 1 month after thermal stress following fire in *Quercus* sp. After controlled heating was applied to Aleppo pine (*Pinus halepensis*), Ducrey et al. (1996) observed a decrease in net photosynthesis and stomatal conductance. In our study, this effect disappeared 3 months after fire treatment, as was observed in a study of maritime pine (Alonso et al. 2002). In an additional study, on Aleppo pine, this decrease continued beyond 3 months and ultimately resulted in the death of trees (Ducrey et al. 1996). In our study, no variations were found in pigment contents of Corsican pine needles between 3 and 18 months after prescribed burning.

The enrichment of N content in Corsican pine needles 7 months after prescribed burning is similar to N enrichment reported in an Aleppo pine forest 4 months after burning (Gillon et al. 1999). Similar increases were found in ponderosa pine at 2 years (Feeney et al. 1998) and 4–6 years (Wallin et al. 2004) following fire. As in the study by Gillon et al. (1999), we did not observe this increase during the first months following burning.

Chemical composition of the foliage, especially in conifers, reflects the soil nutrient content (Wang and Klinka 1997). Indeed, forest soil N and C content are important because they can influence decomposition rates and affect nutrient availability and plant productivity (Fisher and Binkley 2000, Hyvönen et al. 2000). Several studies showed that the concentration of total N and mineral N increases near the soil surface immediately after burning (Covington and Sackett 1986, 1992; Monleon et al. 1997; Ubeda et al. 2005; Moghaddas and Stephens 2007). This could be due to the increase in 1) ashes on soil surface, which are a major source of soil mineral N (Grogan et al. 2000); and 2) microbial mineralization (Covington and Sackett 1986) and development of nitrifying bacteria (Covington et al. 1991). Monleon et al. (1997) reported that inorganic N contents return to normal values 1 year after prescribed burning in ponderosa pines. In pine stands, net nitrogen mineralization and nitrification increase for a period of months or years after prescribed burning (Covington and Sackett 1986, 1992). According to Covington et al. (1991), we can suggest that N contents in soil were mineralized and nitrified during the first months following burning and subsequently absorbed by plants during the rest of the year in Corsican pine stands, which may have positively influenced their performance.

In our study, leaf $\delta^{13}C$ was unaffected by prescribed burning. Zausen et al. (2005) showed less $\delta^{13}C$ content in thinned and burned stands relative to unburned stands. Lower $\delta^{13}C$ was correlated with the increase in water availability in trees (Bush and Smith 1993, Fleck et al. 1996), resulting from decreased tree competition in thinned stands (Zausen et al. 2005). In our study, it seems that prescribed burning did not induce variation in water availability for pines, presumably because only the surface vegetation was burned and did not cause tree mortality. Our results showed no variation in physiological compounds of needles or soil characteristics at 18 months following burning. Others authors showed a similar tendency in leaf $\delta^{13}C$ results at similar longer times-since-burn in pine forests. No variation in leaf $\delta^{13}C$ was found at 2–6 years by Feeney et al. (1998) and Wallin et al. (2004) or at longer intervals by Sala et al. (2005) and Zausen et al. (2005) after prescribed burning and a thinning. It seems that there is no impact at intermediate times (18 months to 4 years) after one prescribed burn in Corsican pine stands.

Impact of the Seasonality of Burning

The response of pigments was more strongly related to time-since-fire rather than season of burn, with greatest decreases in chlorophyll occurring 1 month following fire in both spring and fall. However, decreases were greatest following the spring treatment, attributable to May being a period of higher tree photosynthetic activity than November (Teskey et al. 1994). During the spring the plant is more sensitive to stress. However, this impact on pigment contents is apparently short term given that no variation was observed after 1 month for the two prescribed burns.

MANAGEMENT IMPLICATIONS

In general, the results support the viability of prescribed burning in Corsican pine stands. As pigments decreased more following a spring burn, forest managers could preferentially conduct the prescribed burning during the fall period. However, in either season, prescribed burning appeared to cause only short-term reductions in chlorophyll *a* content and thus photosynthetic potential, which may be in part compensated for by the increases in foliar N, a limiting factor in plant growth. Prescribed burning is important for removing vegetation from the understory of the pine forest and reducing wildfire risk. Low-intensity prescribed burning causes little damage and no mortality for trees, thus making it a good fire prevention tool for Corsican pine, if used with care. However, other factors should be studied to provide further guidance for forest managers, including the effects of prescribed fire on tree growth of Corsican pine and on macrofauna of conservation concern.

LITERATURE CITED

Alonso, M., M.J. Rozados, J.A. Vega, P. Perez-Gorostiaga, P. Cuinas, M.T. Fonturbel, and C. Fernandez. 2002. Biochemical responses of *Pinus pinaster* trees to fire-induced trunk girdling and crown scorch: secondary metabolites and pigments as needle chemical indicators. Journal of Chemical Ecology 28:687–700.

Bush, D.E., and S.D. Smith. 1993. Effects of fire on water and salinity relations of riparian woody taxa. Oecologia 94:186–194.

Carter, M.C., and C.D. Foster. 2004. Prescribed burning and productivity in southern pine forests: a review. Forest Ecology and Management 191:93–109.

Covington, W.W., L.F. Debano, and T.G. Huntsberger. 1991. Soil N changes associated with slash pile burning in pinyon–juniper woodlands. Forest Science 37:347–355.

Covington, W.W., and S.S. Sackett. 1986. Effect of periodic burning on soil N concentrations in ponderosa pine. Soil Science Society of America Journal 50:452–457.

Covington, W.W., and S.S. Sackett. 1992. Soil mineral nitrogen changes following prescribed burning in ponderosa pine. Forest Ecology and Management 54:175–191.

Damesin, C., S. Rambal, and R. Joffre. 1997. Between-tree variations in leaf $\delta^{13}C$ of *Quercus pubescens* and *Quercus ilex* among Mediterranean habitats with different water availability. Oecologia 111:26–35.

Ducrey, M., F. Duhoux, R. Huc, and E. Rigolot. 1996. The ecophysiological and growth responses of Aleppo pine (*Pinus halepensis*) to controlled heating applied to the base of the trunk. Canadian Journal of Forest Research 26:1366–1374.

Feeney, S.R., T.E. Kolb, M.R. Wagner, and W.W. Covington. 1998. Influence of thinning and burning restoration treatments on presettlement ponderosa pines at the Gus Pearson Natural Area. Canadian Journal of Forest Research 28:1295–1306.

Fernandes, P., and H. Botelho. 2004. Analysis of the prescribed burning practice in the pine forest of northwestern Portugal. Journal of Environmental Management 70:15–26.

Fernandes, P.M., and E. Rigolot. 2007. The fire ecology and management of maritime pine (*Pinus pinaster* Ait.). Forest Ecology and Management 241:1–13.

Fisher, R.F., and D. Binkley. 2000. Ecology and management of forest soils. Third edition. John Wiley and Sons, New York.

Fleck, I., D. Grau, M. Sanjosé, and D. Vidal. 1996. Carbon isotope discrimination in *Quercus ilex* resprouts after fire and tree-fell. Oecologia 105:286–292.

Gillon, D., C. Houssard, J.C. Valette, and E. Rigolot. 1999. Nitrogen and phosphorus cycling flowing prescribed burning in natural and managed Aleppo pine forests. Canadian Journal of Forest Research 29:1237–1247.

Grogan, P., T.D. Burns, and F.S. Chapin. 2000. Fire effects on ecosystems N cycling in a Californian bishop pine forest. Oecologia 122:137–144.

Hatten, J.A., D. Zabowski, A. Ogden, and W. Thies. 2008. Soil organic matter in a ponderosa pine forest with varying seasons and intervals of prescribed burn. Forest Ecology and Management 255: 2555–2565.

Hiscox, J.D., and G.F. Israelstam. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany 57:1332–1334.

Hyvönen, R., B.A. Olsson, H. Lundkvist, and H. Staff. 2000. Decomposition and nutrient release from *Picea abies* (L.) Karst and *Pinus sylvestris* L. logging residues. Forest Ecology and Management 126:97–112.

Moghaddas, E.E.Y., and S.L. Stephens. 2007. Thinning, burning, and thin-burn fuel treatment effects on soil properties in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management 250:156–166.

Monleon, V.J., K. Chromack, and J.D. Landsberg. 1997. Short- and long-term effects of prescribed underburning on nitrogen availability in ponderosa pine stands in central Oregon. Canadian Journal of Forest Research 27:369–378.

Rigolot, E. 2000. Le brûlage dirigé en France: outil de gestion et de recherches associées. Pages 165–178 *in* J.A. Vega and R. Vélez (eds.). Actas de la Reunión sobre quemas prescritas 9. Cuadernos de la Sociedad Española de Ciencias Forestales, Madrid, Spain. [In French.]

Sala, A., G.D. Peters, L.R. McIntyre, and M.G. Harrington. 2005. Physiological responses of ponderosa pine in western Montana to thinning, prescribed burning, and burning season. Tree Physiology 25:339–348.

Salisbury, F.B., and C.W. Ross. 1978. Plant physiology. Second edition. Wadsworth Publishing, Belmont, CA.

Teskey, R.O., D. Whitehead, and S. Linder. 1994. Photosynthesis and carbon gain by pine. Ecological Bulletins 43:35–49.

Trabaud, L., and M. Méthy. 1988. Changes in the photosynthesis system of stump shoots produced after fire by two dominant woody species of the Mediterranean garrigues. Acta Oecologica, Oecologia Plantarum 9:229–243.

Ubeda, X., M. Lorca, L.R. Outeiro, S. Bernia, and M. Castellnou. 2005. Effects of prescribed fire on soil quality in Mediterranean grassland (Prades Mountains, north-east Spain). International Journal of Wildland Fire 14:379–384.

Wallin, K.F., T.E. Kolb, K. Skov, and M.R. Wagner. 2004. Seven-year results of thinning and burning restoration treatments on old ponderosa pines at the Gus Pearson Natural Area. Restoration Ecology 12:239–247.

Wang, G.G., and K. Klinka. 1997. White spruce foliar nutrient concentrations in relation to tree-growth and soil nutrient amounts. Forest Ecology and Management 98:89–99.

Waring, R.H., and W.H. Schlesinger. 1985. Forest ecosystems: concepts and management. Academic Press, New York.

Weber, M.G., and S.W. Taylor. 1992. The use of prescribed fire in the management of Canada's forested lands. Forestry Chronicle 68:324–334.

Wellburn, A.R. 1994. The spectral determination of chlorophylls *a* and *b*, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. Journal of Plant Physiology 144:307–313.

Vélez, R. 2000. Los incendios forestales en la Cuenca Mediterránea. Pages 3.1–3.31 *in* R. Vélez (coordinator). La defensa contra incendios forestales: fundamentos y experiencias. McGraw-Hill, Madrid, Spain. [In Spanish.]

Zausen, G.L., T.E. Kolb, J.D. Bailey, and M.R. Wagner. 2005. Long-term impacts of stand on ponderosa pine physiology and bark beetle abundance in northern Arizona: a replicated landscape study. Forest Ecology and Management 218:291–305.