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Belowground Nutrient Dynamics Following Three Harvest Intensities on the Pearl River Floodplain, Mississippi

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ABSTRACT

The influence of clear and partial cut harvests on belowground nutrient cycling processes was examined on the Pearl River floodplain, Mississippi. Foci examined by this study included fine root biomass and detritus, fine root production, fine root nutrient contents, soil respiration rates, and microbial biomass C, N, and P during the first year post-harvest. Both the clearcut and partial cut initially reduced fine root biomass; however, fine root biomass levels within each treatment did not differ at this study's conclusion. Bimonthly fine root production within both the clearcut and partial cut declined initially following harvest; however, net primary production was greatest within the clearcut, followed by the partial cut, and lowest within the control. Soil respiration rates showed strong seasonal trends; however, increased soil respiration rates within the clearcut and partial cut were not found until almost 1 yr post-harvest. Decreased microbial biomass C levels were observed following both harvests. Only the clearcut treatment significantly reduced microbial biomass N. No treatment effects were found regarding microbial biomass P. Herbaceous and woody vegetation recolonization was vigorous within the clearcut and partial cut harvests, strongly influencing fine root production levels and soil respiration rates. It appears that fine roots from naturally recolonizing vegetation play a large role in belowground C storage following disturbance. The rapid increases in fine root production and biomass following both silvicultural methods indicates that, within these ecosystems, the negative influences of harvesting on belowground C and nutrient pools may be short lived.

THROUGHOUT THE USA, riverine systems represent the largest facet of forested wetlands. It is estimated that these forests cover between 6 to 13 million hectares in the U.S. Southeast (Sharitz and Mitsch, 1993). Because of their position at the land-water interface, these ecosystems are active biogeochemically since they buffer impacts from upland areas while also interacting with the floodwaters that pass across the floodplain. Since these ecosystems cover a broad land base, forested floodplains are also valuable sources of timber, and thus forest management activities are a significant anthropogenic disturbance in these ecosystems.

Little information exists regarding the impacts of forest management practices on the biogeochemical processes within floodplain forests. Even less is known about harvesting impacts on belowground processes within these ecosystems, especially the processes controlling labile C pools and nutrient cycling. Developing a better understanding of these impacts is critical, since belowground processes ultimately determine site productivity and ecological function.

Mechanisms controlling soil organic matter formation and abundance are important since organic matter acts as both a source and sink for soil C (Henderson, 1995). Within forested ecosystems, net primary production is related to the amount and depth of soil organic matter, while the quantity of organic matter within the soil is balanced between levels of net primary production and decomposition rates (Paul and Clark, 1996). Thus, changing levels of above- and belowground net primary production as well as mineralization-immobilization patterns will ultimately influence source-sink relationships within these ecosystems.

Fine roots are an important mechanism controlling labile C and nutrient pools in forested ecosystems (Nadelhoffer et al., 1985; Hendrick and Pregitzer, 1996). These pools are partially dependent upon belowground inputs from forest vegetation; thus changing fine root production levels as a result of timber removal may alter levels of belowground net primary production within these ecosystems. Since belowground net primary production is a significant portion of total net primary production (Vogt et al., 1986), changes to the levels of fine root production and biomass as a result of forest management practices may ultimately influence long-term nutrient levels in forest soils.

Forest soils are a major long-term C source, and possibly the principal C sink in undisturbed terrestrial ecosystems (Harrison et al., 1995). To date, a detailed understanding of the influences of harvesting practices on levels of CO_2 efflux remains unclear (Toland and Zak, 1994; Mattson and Swank, 1989; Gordon et al., 1987). Within undisturbed floodplain forests, detrital C processing is strongly influenced by aerobic respiration (Pulliam, 1993); however, few studies have examined the influences of different harvest intensities on C cycling processes within these ecosystems (Londo et al., 1999).

The microbial biomass acts as a short-term labile pool of C and mineral nutrients (Jenkinson and Ladd, 1981). Although the microbial biomass is a relatively small pool of C and nutrients, their activity controls nutrient availability in soils (Holmes and Zak, 1994; Stewart and Tiessen, 1987). Since microbial activity is influenced by forest management practices (Vitousek, 1981), changes in the microbial biomass may provide insight into short-term nutrient availability following disturbance.

The objectives of this study were to quantify the influences of two harvest regimes, clear and partial cutting, on fine root dynamics, C mineralization rates, and microbial processes for a 12-mo period following disturbance.

METHODS

Study Area

The study site was a bottomland hardwood community located on the Pearl River floodplain, Leake County, Missis-

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Table 1. Preharvest fine root biomass, detritus, and phenology (0- to 15-cm depth) on the Pearl River floodplain, Mississippi. Values are pretreatment means ±1 standard error.

Treatment	Fine root biomass		Fine root detritus		Phenology index	
	<1.0 mm	1-2 mm	<1.0 mm	1-2 mm	April 1996	June 1996
	g m^{-2}				No. intersections/screen	
Control	128.8 ± 11.6a	80.7 ± 16.9a	12.0 ± 2.5b	23.6 ± 6.3a	16.3 ± 5.1a	12.4 ± 3.5a
Partial cut	84.8 ± 9.3b	93.2 ± 24.0a	30.8 ± 8.4a	11.2 ± 4.5a	15.5 ± 2.5a	11.4 ± 2.8a
Clearcut	104.9 ± 12.2ab	65.8 ± 15.8a	12.5 ± 2.0b	30.9 ± 9.8a	22.4 ± 8.0a	15.6 ± 6.7a

† Means followed by tbe same letter within tbe same column are not significantly different at the 0.05 level.

sippi. Prior to harvest, the site was occupied by an uneven-aged stand approximately 56 yr old. The overstory of this mixed hardwood community was dominated by oaks, including water oak (*Quercus nigra* L.), swamp chestnut oak (Q. *michauxii* Nuttall), cherrybark oak (Q. *falcata* var. *pagodaefolia* Ell.), willow oak (Q. *phellos* L.), laural oak (Q. *laurifolia* Michx.), southern red oak (Q. *falcata* Michx.), and white oak (*Q. bicolor* Willd.). Sweetgum (*Liquidambar styraciflua* L.) and black gum (*Nyssa sylvatica* Marshall var. *sylvatica*) were also present.

The soil type in the study area is classified as Guyton series. Guyton soils are fine-silty, siliceous, thermic Typic Glossaqualfs. These soils are deep and poorly drained.

Experimental Design and Harvest Methods

All treatment plots were square and 2.0 ha in area. Prior to harvest, January 1996, one 0.04-ha, circular sample subplot was installed near the center of each 2.0-ha treatment plot. The location of a subplot within a treatment was based on preharvest similarities in microtopography, species composition, and basal area. All pre- and post-harvest sampling was conducted within each subplot. A relatively small sampling area was chosen to limit soil variability and possible confounding factors among and within treatments. All possible precautions were taken to limit non-treatment disturbances within each subplot during sampling.

Each of the two replicated blocks contained an unharvested control, a partial cut, and a clearcut treatment. Harvests within the partial cut treatments removed approximately 50% of the pre-existing basal area. For the clearcut treatments, all merchantable and non-merchantable trees larger than 3.8-cm in diameter at breast height were felled; however, only merchantable stems were removed from the site. Harvesting operations were initiated in mid-July 1997 and concluded in late August. Harvesting operations were conducted with ground-based systems utilizing drive-to-tree feller bunchers and rubber-tired skidders. Felled trees were manually topped on site, leaving crowns and residual coarse woody debris within the treatment plots.

Preharvest Measurements and Results

During the winter and spring months preceeding the harvest treatments, baseline measurements were taken to examine and quantify any preharvest differences among treatments. Variables specifically examined prior to harvest included, fine root biomass and detritus, fine root phenology, soil temperature, depth to reduced soil conditions, and soil bulk density within each treatment subplot.

Fine root biomass, detritus, and phenology indices are shown in Table 1. With the exception of the partial cut treatment, preharvest biomass and detritus levels for fine roots <1.0-mm in diameter did not differ. No preharvest differences among treatments were found for both live and dead fine roots 1 to 2-mm in diameter. Fine root phenology, expressed as the mean number of fine root intersections/screen, revealed no preharvest differences among treatments.

Preharvest soil physical measurements are listed in Table 2. Mean daily minimum and maximum soil temperatures did not differ among treatments. No differences were observed among treatments regarding oxygenated soil depth and soil bulk density.

Post-Harvest Measurements

Fine Root Biomass and Detritus

Starting in January 1997, soil cores (13-cm diam, 11-cm depth) were taken to evaluate fine root standing crop bimonthly. In the lab, fine roots were removed from the soil cores by hand, separated into two diameter classes (<1.0 mm and 1-2 mm), and classified as live or dead. Visual criteria were used to distinguish live and dead fine roots. Live fine roots were distinguished by their flexibility and whitish-brown colors, while dead fine roots were usually dark colored, brittle, and often defined by the easy separation of the stele and cortex (Vogt and Persson, 1990). Weights for each diameter class and status were determined after the roots were dried at 70°C and weighed.

Fine Root Net Primary Production

Fine root net primary production was measured by an in situ root screen method, similar to that described by Melhuish and Lang (1968). Melhuish and Lang (1968) demonstrated

Table 2. Preharvest mean daily minimum and maximum soil temperatures, depth of oxygenated soil, aud soil bulk density on the Pearl River floodplain, Mississippi. Values are pretreatment means ±1 standard error.

Treatment	Mean daily minimum soil temperature				
	February	March	April	May	June
	°C				
Control	9.5 ± 0.5a	9.1 ± 0.4a	14.3 ± 0.3a	19.1 ± 0.2a	20.2 ± O.lb
Partial cut	9.6 ± 0.5a	9.4 ± 0.4a	14.1 ± 0.4a	19.4 ± 0.2a	20.5 ± 0.1a
Clearcut	103 ± 0.7a	9.9 ± 0.5a	14.8 ± 0.3a	19.2 ± 0.2a	203 ± 0.1b

Treatment	Mean daily maximum soil temperature				
	February	March	April	May	June
	°C				
Control	12.2 ± 0.6a	12.1 ± 0.4a	15.9 ± 0.2a	19.8 ± 0.2a	21.2 ± 0.1a
Partial cut	12.0 ± 0.6a	12.1 ± 0.4a	16.0 ± 0.3a	20.2 ± 0.2a	21.0 ± 0.2a
Clearcut	12.4 ± 0.8a	12.3 ± 0.5a	16.2 ± 0.2a	19.9 ± 0.2a	21.0 ± 0.2a

Treatment	Oxygenated soil depth		Soil bulk density
	April %	June %	June %
	cm		Mg m^{-3}
Control	31.0 ± 3.0a	55.8 ± 5.0a	1.08 ± 0.05a
Partial cat	24.0 ± 4.3a	63.5 ± 4.7a	1.05 ± 0.01a
Clearcut	31.0 ± 3.7a	64.4 ± 5.0a	1.03 ± 0.01a

† Means followed by the same letter within tbe same column are not significantly different at the 0.05 level.

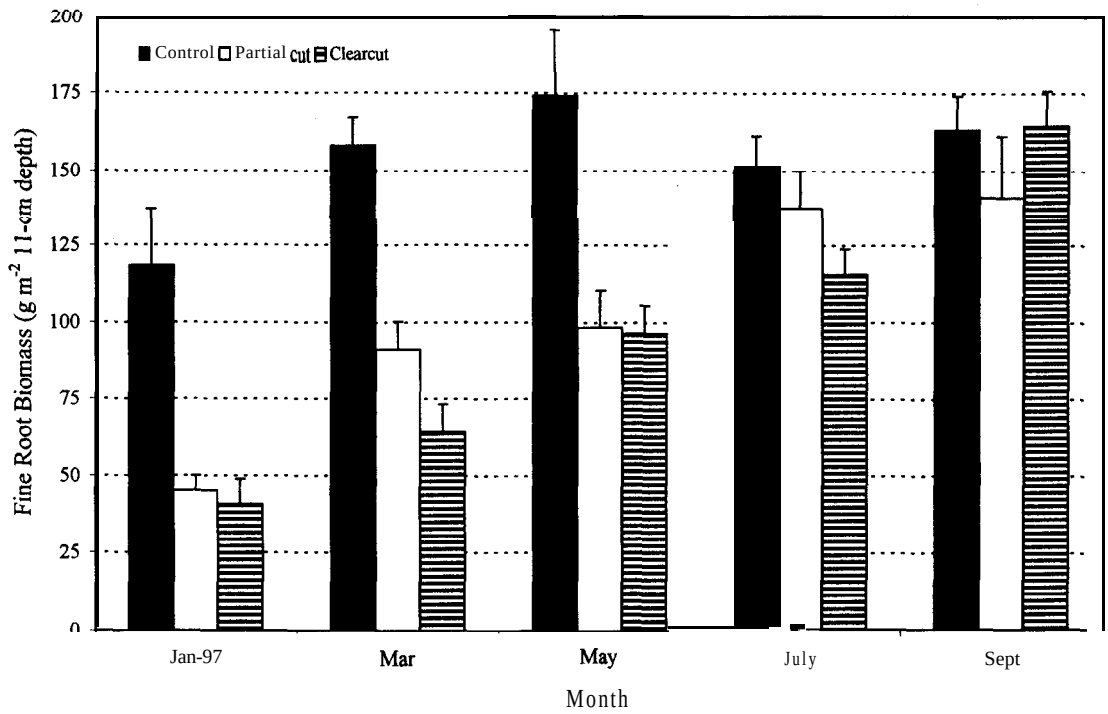

Fig. 1. Fine root biomass (g m^{-2} 11-cm depth, roots <2.0 mm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

a theoretical relationship between the number of fine roots intersecting a plane of known area and the probable total fine root length per unit volume soil using the equation $L_v = 2n$. For this equation, L_v is equal to the probable total fine root length per unit volume soil [cm of fine roots/cm' of soil], while n equals the number of fine root intersections per screen [No. of intersections/screen area (cm')].

In September 1996, fine root screens (15.2-cm length, 7.6-cm width, 10 by 10 holes per inch) were inserted into the soil using a narrow shovel, at a 45" angle, randomly oriented, to

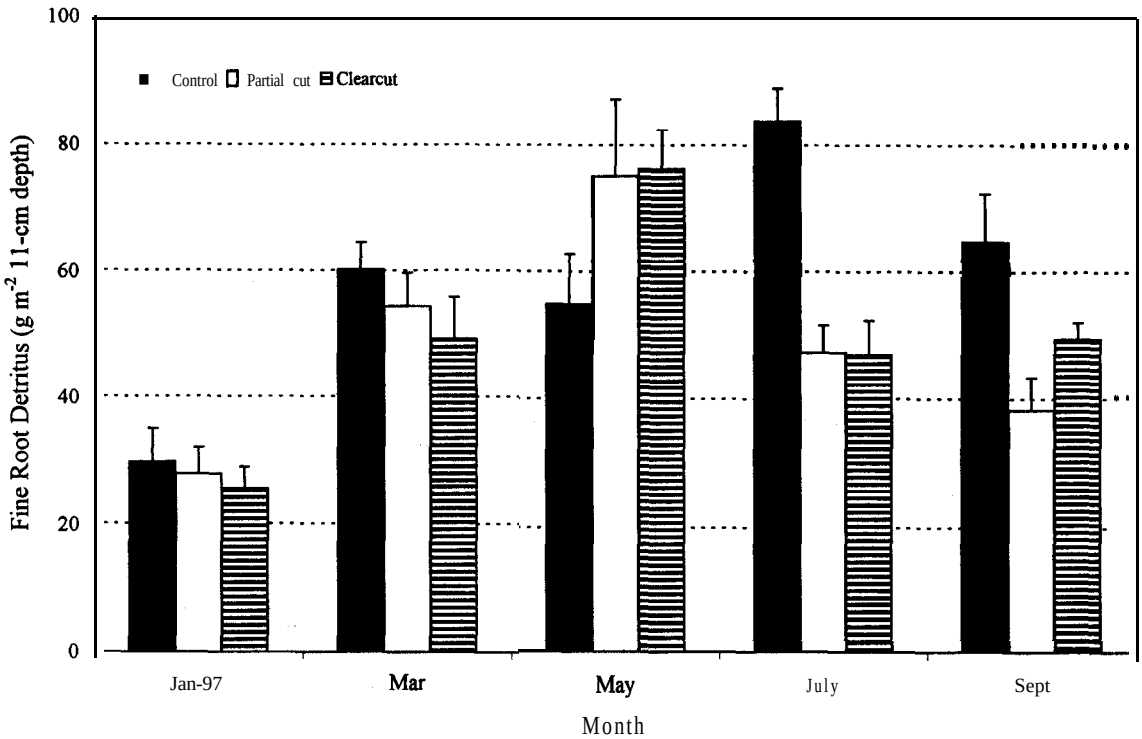

Fig. 2. Fine root detritus (g m^{-2} 11-cm depth, roots <2.0 mm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

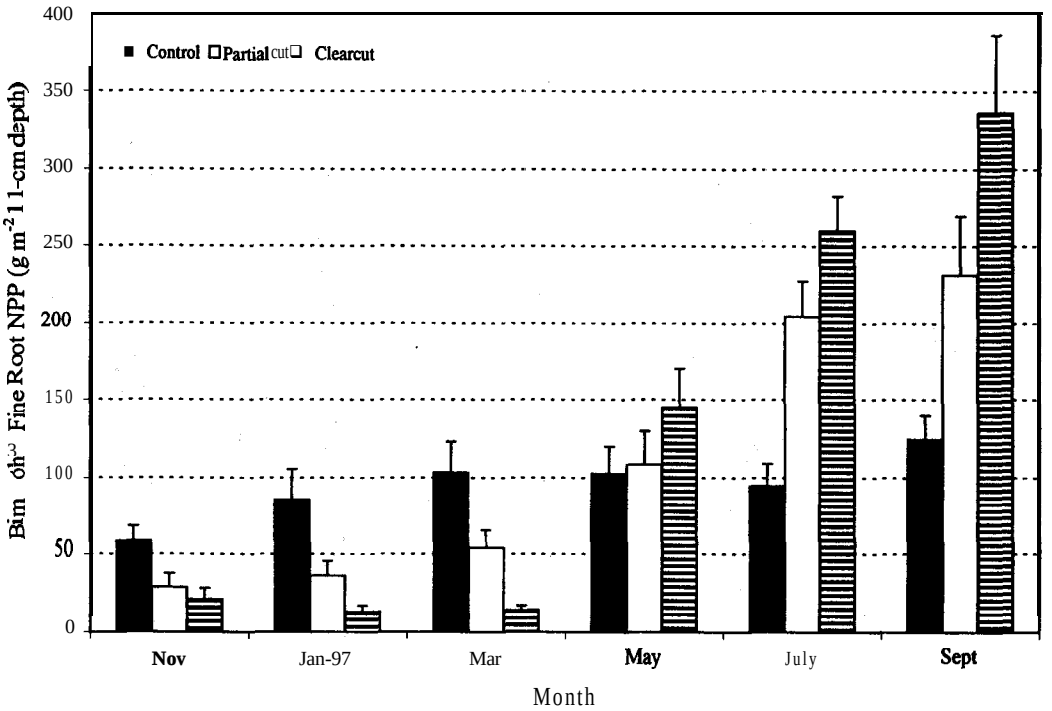

Fig. 3. Bimonthly fine root production (g m^{-2} 11-cm depth, live roots <2.0 mm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

a vertical depth of 11 cm. Starting in November 1996, and continuing bimonthly, fine root screens were randomly selected and removed from within each subplot. Extracted screens were sealed in plastic bags and stored at 4°C until analyzed. In the lab, the soil surrounding each screen was gently removed with a low-pressure water wash and the number of intersections for each fine root diameter class was recorded.

Since the fine root screens calculate production as a length, a length/weight conversion ratio was created for each diameter class to express fine root production on a weight basis. Mean weights per centimeter of root for each diameter class were then multiplied by the length calculated from the fine root screens to express fine root net primary production as a biomass per unit volume of soil.

Fine root net primary production was determined after differencing levels of fine root production between subsequent sample periods, then adding all positive differences to the production estimate from the first collection date.

Fine Root Nutrient Analysis

Fine root nutrient analyses were performed for each fine root diameter class and status, within each soil core, for each sample period. Dried fine roots were ground either with a Wiley mill or by hand with a mortar and pestle. Total C and N analyses were conducted with a Perkin Elmer Series II CHNS/O Analyzer 2400 (Perkin Elmer Corp., Norwalk, CT). Phosphorus analyses were performed after roots were dry ashed and taken up in dilute HCl. Total P analyses were performed with a Spectronic 501 spectrophotometer (Milton Roy Co., Rochester, NY).

Soil Respiration

Carbon dioxide evolution was measured by soda lime absorption. Cylindrical chambers, each covering 615.75 cm^2 of soil, were used to enclose the soda lime adsorbent in the field. Prior to field incubation, no. 12 grade soda lime was dried to a constant mass (100°C, 48 h). Thirty-seven grams of soda lime was placed into containers and housed underneath each chamber during field incubation. After 24 h of field incubation, the soda lime containers were dried (100°C, 24 h) and weighed. The difference in soda lime weight gain was multiplied by 1.41 to express the data in terms of CO_2. Soil respiration measurements were initiated in September 1996 and continued bimonthly.

Microbial Biomass Carbon, Nitrogen, aud Phosphorus

Microbial biomass C, N, and P levels were measured by chloroform fumigation-extraction procedures similar to those outlined by Brooks et al. (1985), Vance et al. (1987), and Hedley and Stewart (1982), respectively. For microbial biomass C and N analysis, 18.5 g of sieved field moist soil was used, while 15 g of soil was used for microbial biomass P. Fumigated samples were placed in vacuum desiccators and fumigated with ethanol-free chloroform for 24 h at room temperature while in total darkness. Both fumigated and nonfumigated microbial biomass C and N samples were extracted with 125 mL of 0.5 mol L^{-1} K_2SO_4. Microbial biomass P samples were extracted with 100 mL of 0.5 mol L^{-1} $NaHCO_3$. After 30 min of extraction with a box shaker, solutions were filtered and stored at 4°C until analysis.

Dissolved organic C was measured with a Dohrmann DC 80 total organic C analyzer (Rosemount Analytical Inc., Santa Clara, CA). Total N was determined by Kjeldahl analysis. Total P was measured by an ascorbic acid method (Kuo, 19%). Microbial biomass values are expressed on the basis of oven-dried soil (μg g^{-1} dry soil-').

Soil Measurements

Soil bulk density was measured by the soil ped method (Blake and Hartge, 1986). In the field, soil peds were obtained with a small shovel from two depths, 0 to 13 and 13 to 25 cm.

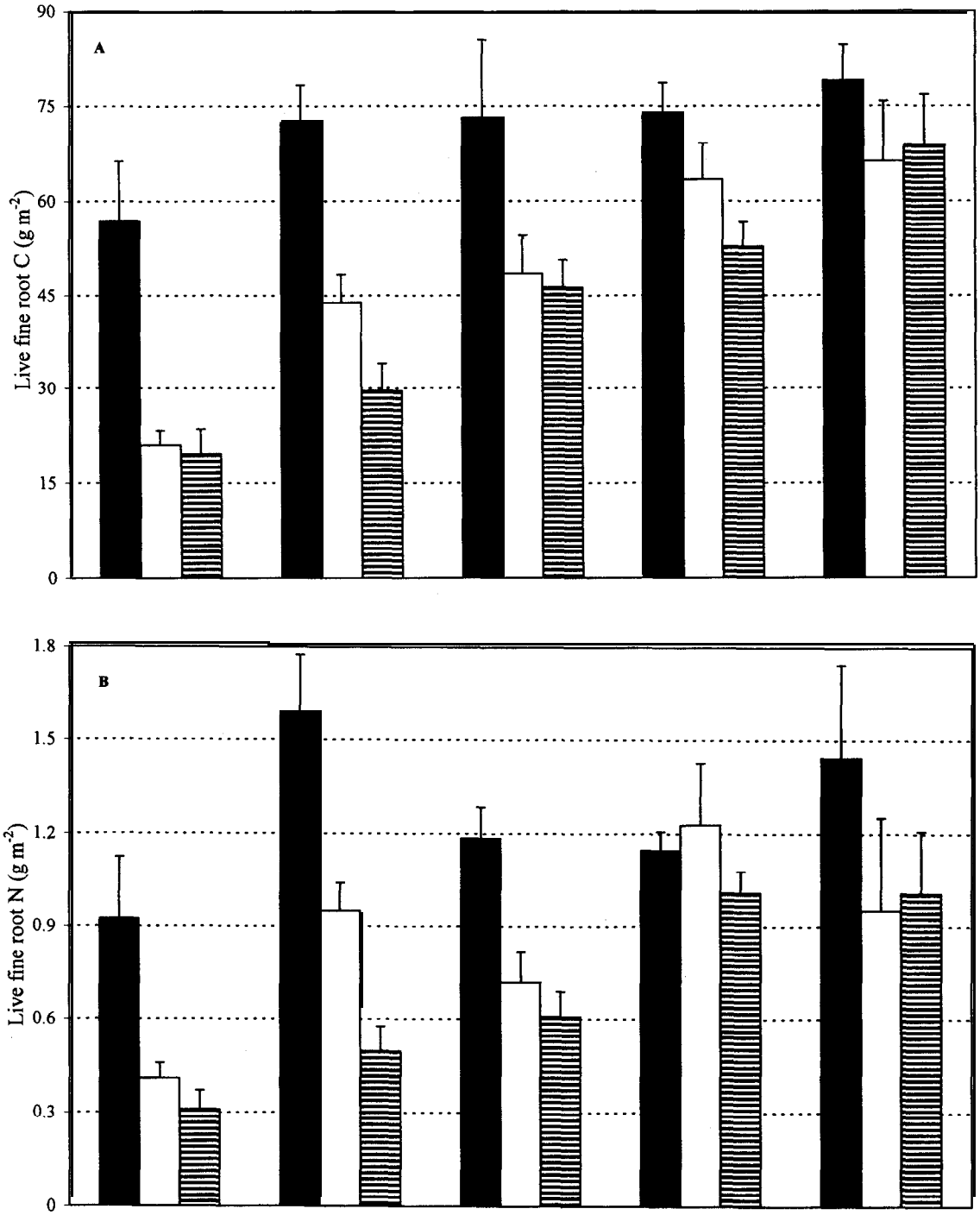

Fig. 4. Live tine root C (A), N (B), and P (C) contents (g m^{-2} 11-cm depth, roots <2.0 mm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

All peds were attached to copper wire and dipped into a Saran resin and acetone solution (Saran resin; Dow Chemical Co., Midland, MI). In the laboratory, peds were dried (105°C, 48 h) and weighed. Ped volume was determined by displacement in water.

Soil temperatures were recorded with miniature data loggers (Onset Computer Corp., Pocasset, MA). Data loggers were placed 5 cm below the soil surface within each subplot for the studies' duration.

Changes in soil oxidation states were evaluated by a steel rod oxidation method (Carnell and Anderson, 1986). Steel welding rods, 76 cm in length, were positioned throughout each subplot and collected bimonthly. The depth of rust was measured to estimate the zone of oxygenated soil.

Statistical Analysis

Data were analyzed by the general linear model (GLM) procedure of the Statistical Analysis System (SAS Inst., 1991). To test for differences among treatments, the block x treatment interaction error term was used in an analysis of variance comparison. Duncan's New Multiple Range Procedure was

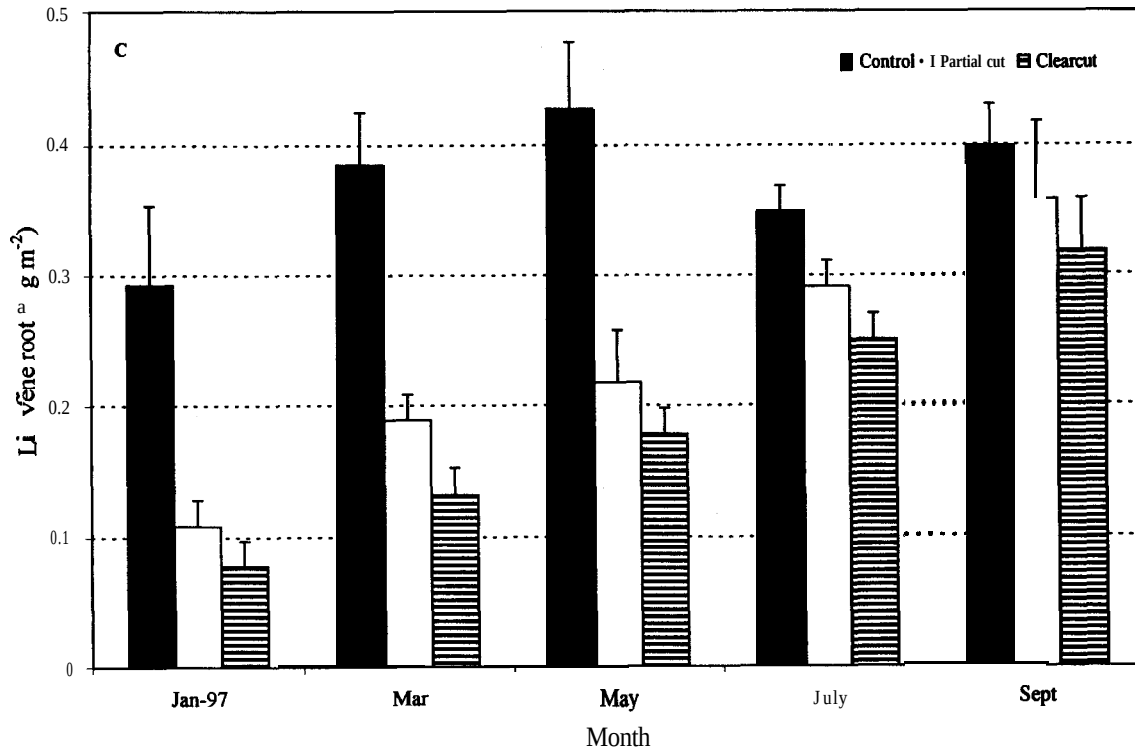

Fig. 4. Continued.

used to separate means following significant results. All differences are reported as significant at the 0.05 level.

RESULTS

Fine Root Biomass and Detritus

Fine root biomass for both silvicultural methods and the control are shown in Fig. 1. Fine root biomass within the control exceeded biomass levels within the clearcut and partial cut during the January, March, and May 1997 sample dates. In July 1997, only fine root biomass within the clearcut differed from the control. No treatment effects on fine root biomass were measured in September 1997. Examining fine root detritus revealed no clear trends at each sample date for the control, clearcut, and partial cut (Fig. 2).

Fine Root Net Primary Production

Bimonthly fine root production determined with the root screens is shown in Fig. 3. Compared with the control, fine root production within the clearcut and partial cut treatments was lower during the winter and early spring months following harvest; however, only the clearcut showed a decline in fine root production. In May 1997, fine root production did not differ among treatments. For the remainder of the growing season, however, fine root production within both the clearcut and partial cut exceeded that of the control. Annual fine root net primary production was greatest within the clearcut (308.7 g m^{-2}), followed by the partial cut (278.5 g m^{-2}), and lowest within the control (171.9 g m^{-2}).

Fine Root Nutrient Contents

Fine root C, N, and P contents for live and dead fine roots are shown in Fig. 4 and 5, respectively. Fine root C, N, and P levels within each treatment mirrored changes in the levels of fine root biomass and detritus.

Soil Respiration

Overall, soil respiration rates showed strong temporal trends (Fig. 6). Immediately following harvest, soil respiration within the partial cut exceeded that of the control and clearcut. Soil respiration rates were similar within clearcut, partial cut, and control during the winter and spring sample dates. In July and September 1997, higher soil respiration rates were recorded within both the clear and partial cut.

Microbial Biomass Carbon, Nitrogen, and Phosphorus

At both sample dates, microbial biomass C and harvest intensity were inversely related (Table 3). Compared with the control, microbial biomass N was lower within the clearcut treatment at both sample dates, while microbial biomass N for the partial cut declined at the May 1997 sample date. No treatment effects were found regarding microbial biomass P at either sample date.

Soil Measurements

When compared with the control, both the clearcut and partial cut increased soil bulk density at the two depths, 0 to 13 cm and 13 to 25 cm (Table 4).

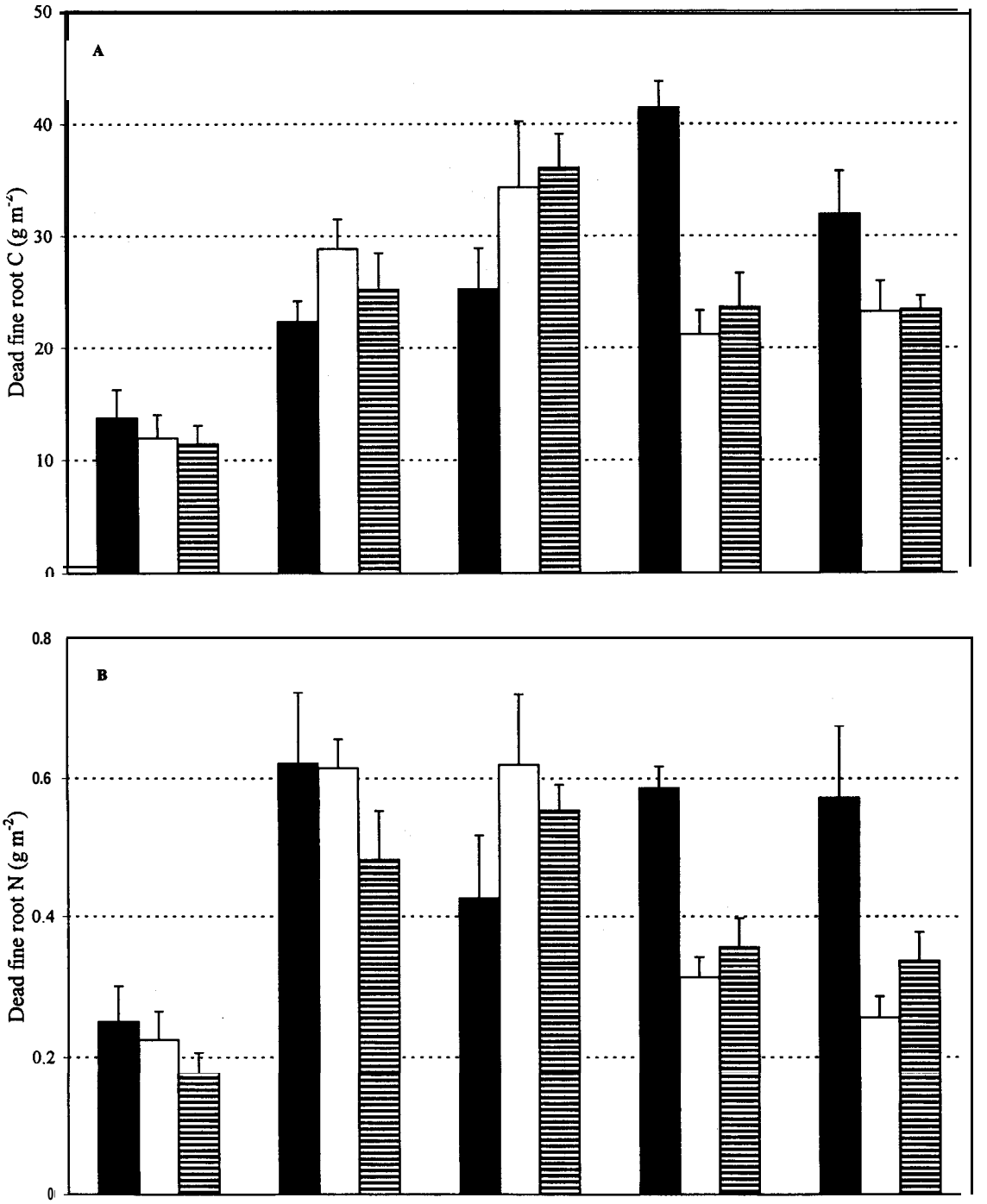

Fig. 5. Dead fine root C (A), N (B), and P (C) contents (g m^{-2} 11-cm depth, roots <2.0 mm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

Mean monthly maximum and minimum soil temperatures are shown in Fig. 7. Maximum daily soil temperatures within both the clearcut and partial cut exceeded the control in October 1996 and from March to September 1997. Mean daily minimum soil temperatures within the clearcut and partial cut both exceeded the control during the late spring and summer sample dates.

No significant treatment effects on the depth of soil oxidation were found at any sample date (Fig. 8). For each treatment, the depth of oxidation did change temporally, being shallowest in the winter-early spring and deepest in the fall.

DISCUSSION

Fine Root Biomass

Live fine root biomass, within the control, showed little temporal variation, while fine root biomass within both the clearcut and partial cut increased throughout the study. Seasonal fluctuations in fine root biomass

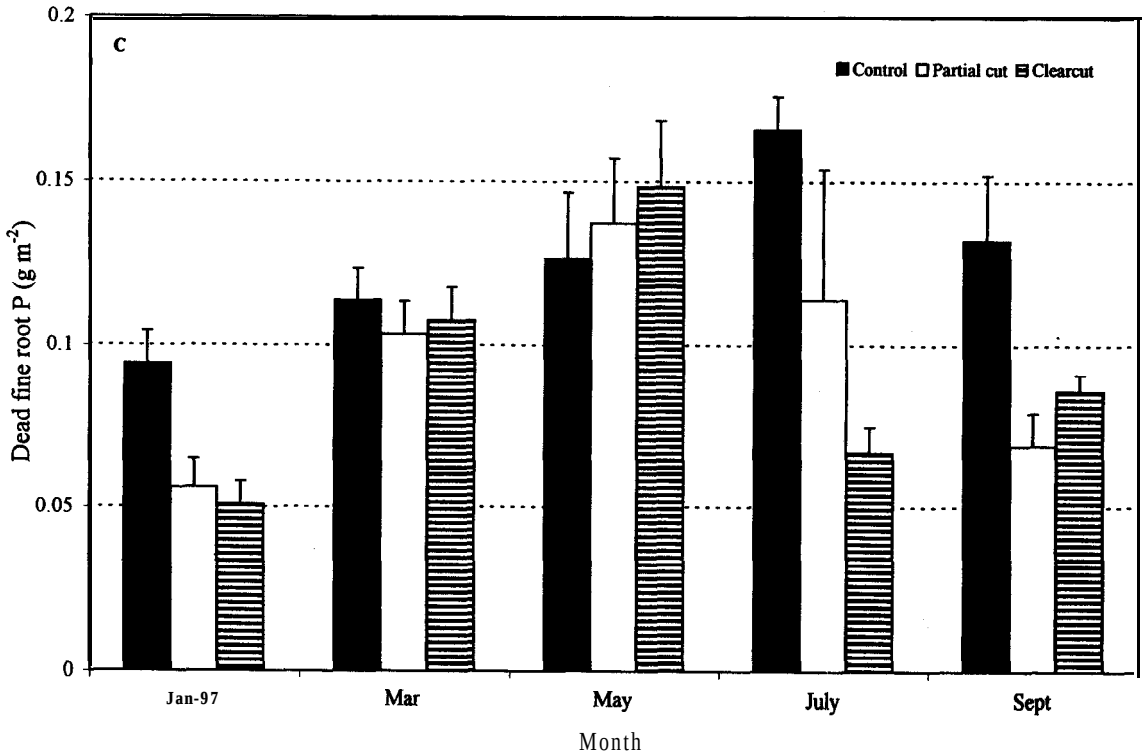

Fig. 5. Continued.

have been demonstrated within unharvested forest systems (Vogt et al., 1981; Burke and Raynal, 1994; Hendrick and Pregitzer, 1996) and following both clearcut and partial cut harvests (Yin et al., 1989). For this study, fine root biomass recovery within both the clearcut and partial cut was rapid during the first year following harvest. In July 1997, fine root biomass within the partial cut did not differ from the control. At the September 1997 sample date, no treatment effects were observed. In the years following harvest, increased fine root biomass within both the clearcut and partial cut harvests has been observed (Yin et al., 1989). However, the data from this study indicate that, within these ecosystems, fine root biomass recovery is rapid during the initial months following disturbance.

Fine Root Net Primary Production

For the first year post-harvest, fine root net primary production within both the clearcut and partial cut treatments exceeded that of the control. Annual fine root net primary production was greatest within the clearcut, followed by the partial cut, and lowest in the control. Yin et al. (1989) observed the same trends in fine root production following clearcut and partial cut harvests within a *Quercus* ecosystem. The fine root production estimates from this study are in the range reported by Powell and Day (1991) for their maple-gum communities within the Great Dismal Swamp. However, the fine root production estimates from the mixed hardwood community of Powell and Day (1991) exceeds our levels, and this community appears to more closely resemble our study site in terms of flooding regime, species composition, and stand age.

The use of root screens to estimate levels of fine root net primary production within floodplain forests is limited to few studies. Using root screens, Baker (1998) found that fine root net primary production ranged between 93.7 and 180.3 g m^{-2} within different wetness categories of the Coosawhatchie River floodplain in South Carolina. Fine root net primary production estimates for Clawson et al. (1996, unpublished data) ranged between 56.2 and 211.1 g m^{-2} along a wetness gradient on the Flint River floodplain in Georgia. Overall, the fine root production estimates from this study are within the ranges reported for wetland (Symbula and Day, 1988; Jones et al. 1996) and upland forests (Joslin and Henderson, 1987; Nadelhoffer and Raich, 1992; Burke and Raynal, 1994).

Fine root net primary production within both the clearcut and partial cut exceeded the control during the first year post-harvest. The rapid recovery in fine root biomass and higher levels of fine root production during the first year post-harvest indicate that for this system, the negative influences of harvesting on fine root dynamics were short lived. Rapid increases in fine root biomass, following anthropogenic disturbance, have been observed (Raich, 1980). The rapid increases in fine root biomass and production within both the clearcut and partial cut strongly influenced fine root nutrient contents, indicating that fine roots are a strong nutrient sink following disturbance.

Soil Respiration

For this study, temporal variation in soil respiration between the clearcut, partial cut, and control was simi-

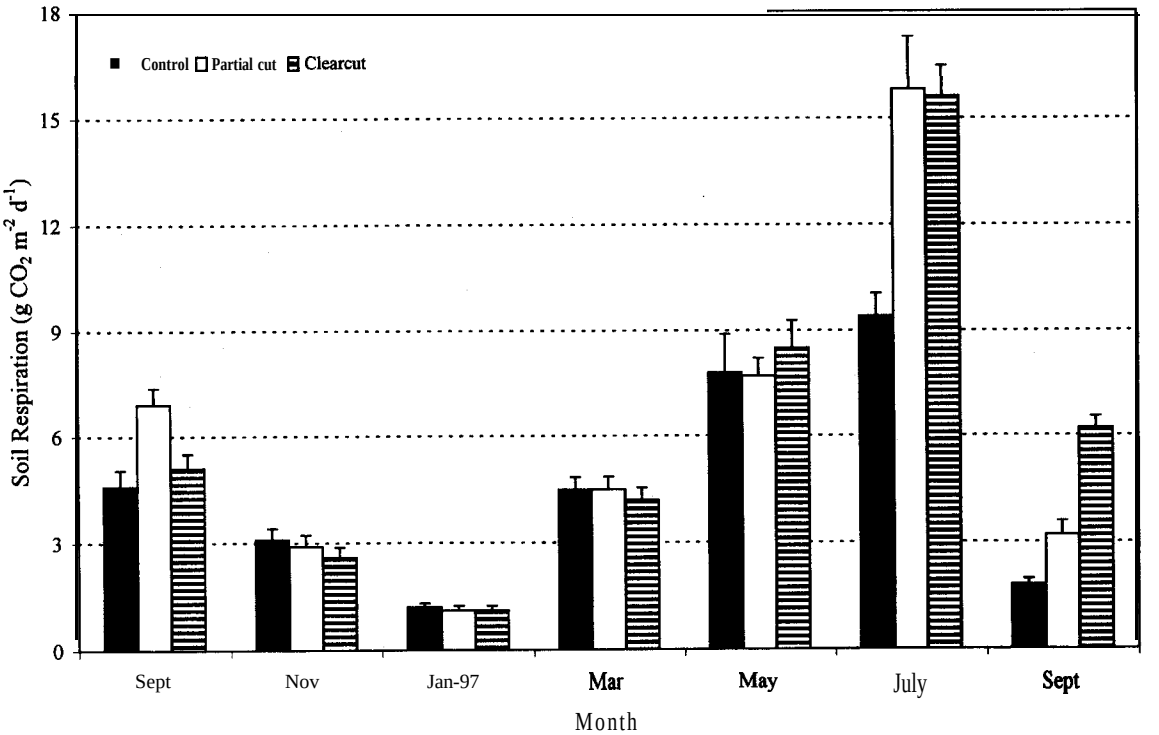

Fig. 6. Soil respiration (g CO, m^{-2} d^{-1}) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

lar. Soil respiration was greatest during midsummer, reaching a maximum in July, and lowest during the fall and winter months. This temporal pattern is similar to that reported by Toland and Zak (1994) for a northern hardwood forest and Edwards and Ross-Todd (1983) for a mixed hardwood forest in Tennessee.

During the initial period following harvest, soil respiration levels did not differ among treatments. Londo et al. (1999) noted that soil respiration rate differences among treatments appeared greater in warmer months compared with colder months within an East Texas bottomland hardwood forest, The similar soil respiration rates during the dormant period of this study differ from those of Edwards and Ross-Todd (1983) who found increased soil respiration rates in their intensively harvested watersheds during the dormant season.

In the present study, the July 1997 sample period revealed significantly increased soil respiration rates for both the clearcut and partial cut. This was a period when herbaceous and woody vegetation was rapidly recolonizing both the clearcut and partial cut harvests. The regrowth within the clearcut was greatest with complete ground cover, while the partial cut exhibited a lesser degree of ground cover. For harvested forest systems with minimal soil disturbance, followed by rapid natural revegetation, minor changes in soil respiration rates have been observed (Edwards and Ross-Todd, 1983; Nakane et al., 1986).

For this study, fine roots may be the largest contributors to total soil respiration. Increased fine root production and biomass within both the clearcut and partial cut harvests corresponded temporally to increased soil respiration rates within both the clearcut and partial cut harvests. Londo et al. (1999) indicated that herbaceous

Table 3. Microbial biomass C, N, and P following each harvest intensity on the Pearl River floodplain, Mississippi. Values are means ±1 standard error.

Biomass	Treatment	Sample date	
		September 1996	May'1997
		μg g^{-1}	
Carbon	Control	1660 ± 194a	2511 ± 152a
	Partial cut	1403 ± 81ab	1980 ± 136b
	Clearcut	1172 ± 72h	1884 ± 85b
Nitrogen	Control	154.7 ± 16a	158 ± 9a
	Partial cut	143.7 ± 9ab	117 ± 12b
	Clearcut	95.3 ± llb	95.2 ± 'lb
Phosphorus	Control	1.10 ± 0.4a	17.96 ± 6.8a
	Partial cot	0.61 ± 0.2a	17.98 ± 9,3a
	Clearcut	0.67 ± 0.2a	7.97 ± 2.6a

† Means followed by the same letter within the same column are not significantly different at the 0.05 level.

Table 4. Soil bulk density following each harvest intensity on the Pearl River floodplain, Mississippi. Values are mean ±1 standard error.

Treatment	0- to 13-cm depth	13- to 25-cm depth
	Mg m^{-3}	
Control	1.01 ± 0.06b	1.17 ± 0.04b
Partial cnt	1.37 ± 0.03a	1.36 ± 0.05a
Clearcut	1.32 ± 0.03a	1.36 ± 0.02a

† Means followed by the same letter within the same column are not significantly different at the 0.05 level.

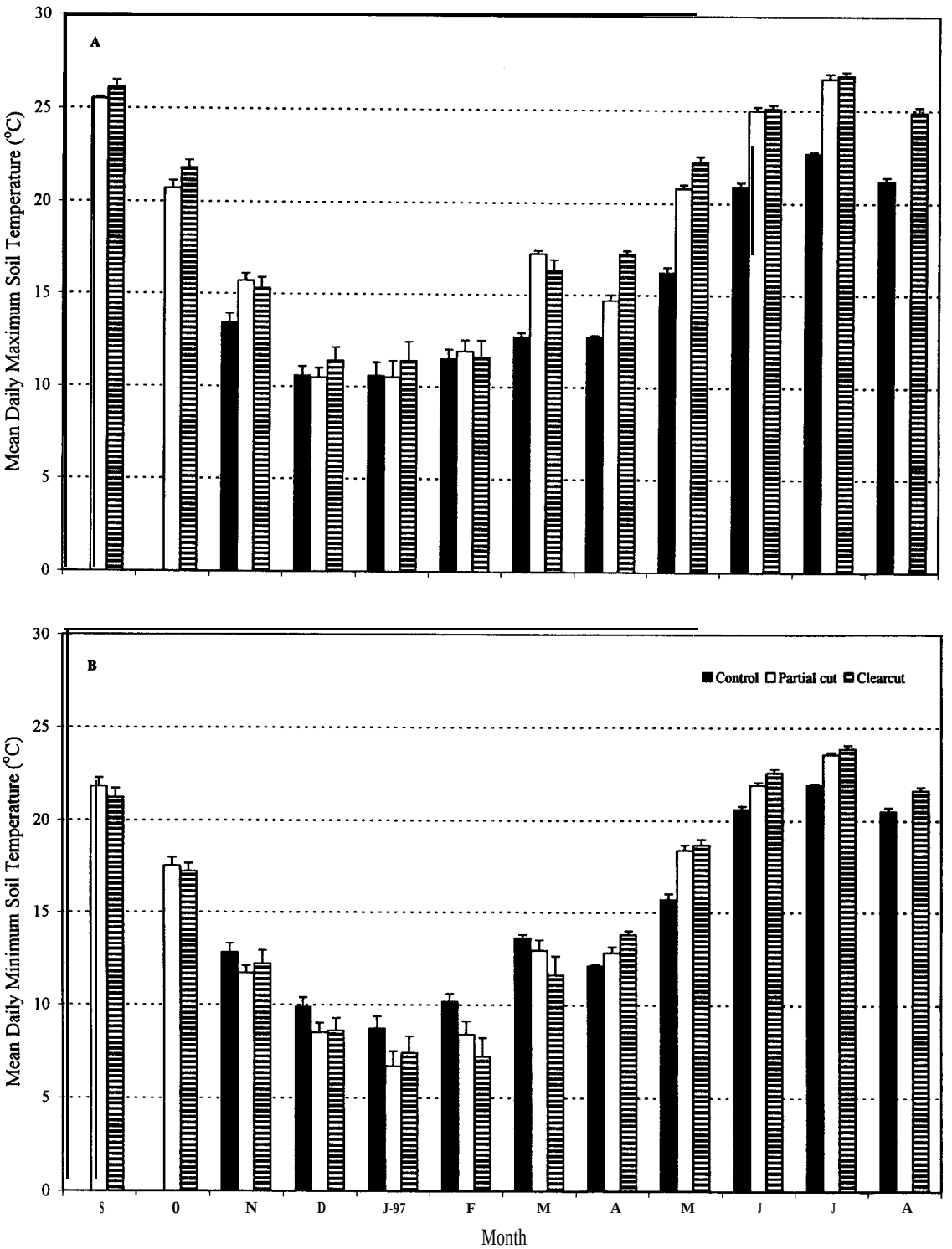

Fig. 7. Mean daily maximum (A) and minimum (B) soil temperatures (°C) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

vegetation and sprouting hardwoods were the primary contributors to increased in situ soil respiration rates within their clearcut and partial cut plots. Fine root contributions to overall soil respiration in unharvested forests have varied; however, it appears that between 35 to 62% of the total soil respiration is root derived (Nakane et al., 1983; Ewe11 et al., 1987; Pulliam, 1993). Even though fine root respiration within the clearcut and partial cut plots may have been the significant contributor to this studies' increased C efflux, increased C assimilation into fine roots of the recolonizing vegetation ultimately limited losses.

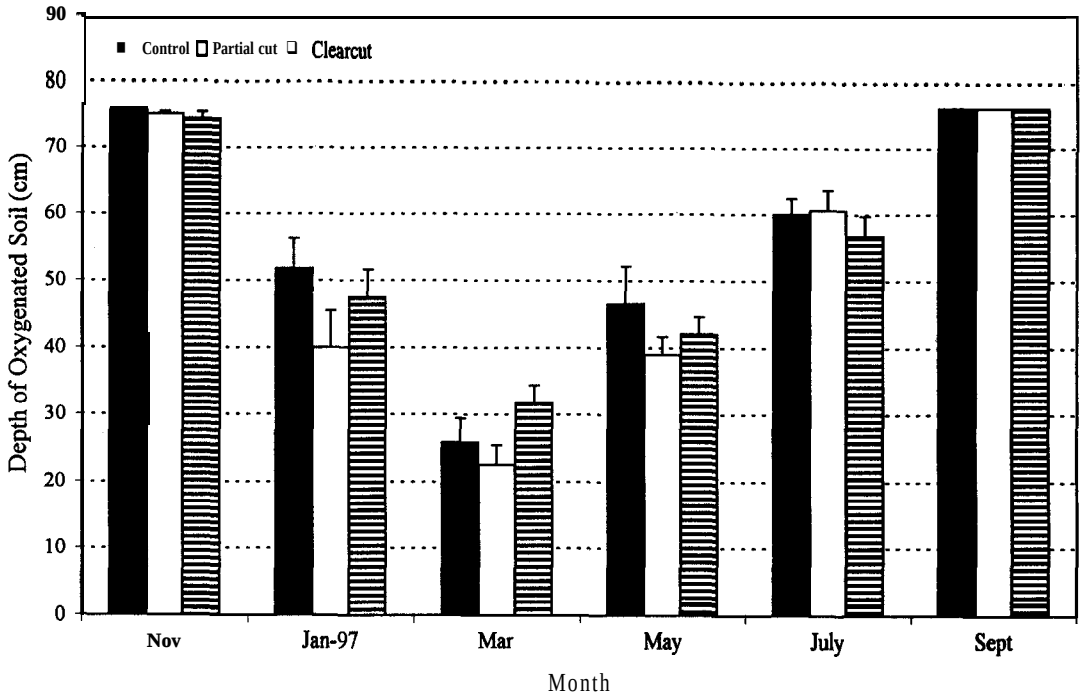

Fig. 8. Depth of oxygenated soil (cm) following each harvest intensity on the Pearl River floodplain, Mississippi. Error bars represent 1 standard error.

Microbial Biomass Carbon, Nitrogen, and Phosphorus

At both sample dates, microbial biomass C declined as a result of both silvicultural methods. The clearcut treatment resulted in the lowest microbial biomass C measured. Declines in microbial biomass C have been observed following clearcutting (Pietikainen and Fritze, 1995). However, increased microbial biomass C following clearcutting has also been reported (Entry et al., 1986; Lundgren, 1982).

Soil temperature and potential concomitant effects on moisture within the harvest plots at the time of sampling may have been the principle abiotic factors limiting microbial biomass size and activity. In September 1996, mean daily maximum soil temperature within both clearcut and partial cut plots exceeded 25°C. In May 1997, mean daily maximum soil temperature within the clearcut exceeded the soil temperatures within the partial cut and control. It is conceivable that the soil environment following both silvicultural methods may have been unfavorable for increased microbial growth as a result of increased soil temperatures and decreased gravimetric soil water.

Variation between the results of this study compared with those cited previously may be explained by differences between ecosystem types and climate. The studies by Entry et al. (1986) and Lundgren (1982) were conducted in northern forest ecosystems. In northern climates, increased soil temperatures following clearcutting may not be enough to affect negatively microbial growth and activity. Thus, clearcutting may create favorable conditions that increase microbial biomass size and activity within these systems.

Clearcutting also reduced levels of microbial biomass N. Similar microbial biomass N values were found at both sample dates for the control and clearcut; however, microbial biomass N declined within the partial cut treatment from September 1996 to May 1997. Overall, the microbial biomass N values from this study are similar to those reported for the mineral soil of a white oak-red maple forest in North Carolina (Gallardo and Schlesinger, 1990).

Microbial C/N ratios have been suggested to be a useful indicator of N availability in forest soils (Chang et al., 1995; Edmonds and Chappell, 1994). In September 1996, C/N ratios for the control (9.8), clearcut (11.0) and partial cut (10.7) were narrow and not different. The May 1997 sample date showed widening C/N ratios for both the clearcut and partial cut treatments (20.7 and 19.6, respectively); however, similar microbial biomass N levels, revealed no trends in microbial immobilization and mineralization rates. For the partial cut, the decline in microbial biomass N indicated a trend towards increasing N mineralization.

The microbial biomass P values in this study were not significantly affected by either silvicultural method. The low microbial biomass P values for all treatments in September 1996 are disturbing; however, no treatment effects were observed during either sample date. Across sample dates, patterns for microbial biomass P did not reflect those of microbial biomass N. The lack of significant treatment effects may, in part, be the result of non-deficient soil P levels across the study area. A preharvest soil nutrient analysis revealed that extractable soil P for the upper 15 cm of soil ranged from 5 to 8.5 mg kg^{-1}. At this range, extractable soil P levels are not limiting

to hardwoods (Harvey Kennedy, 1997, personal communication). Thus, the availability of soil P may have reduced tendencies for immobilization by microbes.

Soil Measurements

Within forested floodplain ecosystems, ground-based harvesting operations have been shown to increase soil bulk density, reduce saturated hydraulic conductivity, and both increase and decrease soil water tables (Aust and Lea, 1992; Lockaby et al., 1994; Messina et al., 1997). In this study, both silvicultural methods significantly increased soil bulk density. Compared with the control, post-harvest soil bulk density at the 0- to 13-cm depth was 26 and 23% higher within the partial cut and clearcut treatments, respectively. Messina et al. (1997) found a similar trend of increased soil bulk densities within clearcut and partial cut harvests.

A primary impact of soil compaction is impeded root development through mechanical resistance and restricted aeration. While the bulk density increases observed in this study were significant, harvesting did not influence levels of soil oxygenation among treatments. Increased soil bulk density within the clearcut and partial cut harvests did not appear to restrict root development based on the fine root production and biomass values. The high levels of fine root production and biomass within both silvicultural methods may, in fact, aid in the recovery of soil bulk density after harvest.

CONCLUSIONS

From this study, some important conclusions regarding harvesting influences on belowground processes may be drawn. Both the clearcut and partial cut harvests initially decreased levels of fine root biomass; however, fine root recovery within these treatments was rapid during the first year post-harvest. The rapid increase in fine root biomass and production following both harvests was a result of vigorous herbaceous and woody vegetation recolonization. Increased soil respiration within both the clearcut and partial cut appeared to be in response to increased fine root production and biomass. The clearcut and partial cut treatments did not consistently or significantly increase soil respiration rates until almost 1 yr post-harvest. Both the clearcut and partial cut reduced microbial biomass C and N levels.

During the first year post-harvest, increased fine root biomass and production following clear and partial cutting indicates that, within these ecosystems, the negative influences of harvesting on belowground nutrient cycling processes may be short lived. It appears that fine roots play a large role in C and nutrient storage following these disturbances.

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