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Soil temperatures during burning of large amounts of wood, effects on soil pH and subsequent maize yields.

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Abstract
Little information is available on the temperatures attained during burning and the immediate changes of soil chemical properties. Soil temperature was measured during, and soil pH changes after burning 10, 1000, 3000 and 5000 Mg ha^{-1} of wood, representing fuel loads (FL) of fallow and tree boles commonly burned for land preparation in southern Cameroon. Burning of 10 Mg ha^{-1} (fallow) caused no discernable temperature increases at any depth. Burning 1000, 3000 and 5000 Mg ha^{-1} of wood, reached mean temperatures of 770°C at the soil surface and 214°C at 5 cm depth, without differences between FLs. At 10 cm depth 133 to 208°C were reached At 20 cm depth 3000 and 5000 Mg ha^{-1} FL exceeded 105°C, 1000 Mg ha^{-1} FL reached 52°C. At 30cm no differences were found (32 to 68°C). At 24 hours after ignition, soil at 10 Mg ha^{-1} FL was at ambient temperature. At 3, 5, 10, and 12 cm depth temperatures were different between all FLs. Soil pH in 0-5 cm depth, increased within 9 days after burning (DAB) from 6.5 to 8.0 at 1000, 3000, and 5000 Mg ha^{-1} FL. At 3000, and 5000 Mg ha^{-1} FL the pH continued to increase until 37 DAB, reaching 9.25. The pH pattern with soil depth did not change between 37 and 79 DAB. Maize yields were significantly reduced when planted immediately after burning FLs of 3000 and 5000 Mg ha^{-1}, mainly caused by low crop establishment. A second crop planted in the following season had a reverse yield response with higher yields after burning high amounts of wood.

Introduction

Slash and burn agriculture is still the dominant form of food production on an estimated 36 million km^2 of land, representing about 30% of the global soil resource in Africa, Asia and South America. Fuel loads after forest clearing can be extremely heterogeneous. In southern Cameroonian forest slash and burn fields, patches and lines, bare of crops and weeds are common. The soil in such places is either bright red or covered with a gray layer of ash, apparently caused by severe burns of large boles. In such areas it may take up to 9 months for vegetation to establish. Severe burns affect about 2 - 8 % of the surface. However, on this small proportion of land, a major proportion of nutrients is deposited, which may be leached into deeper layers, altering the soil pH profoundly. In addition to the effects caused by the heat, changes in soil chemical properties may affect crop performance.
This study simulated the *in situ* burning of boles commonly found in slash and burn forest clearings, to determine: (1) the temperatures attained during the burn, (2) the depth to which the heat penetrates the soil, (3) the changes in soil pH due to the ash produced in the burn, and (4) the immediate effect of such burns on crop growth and yield.

Materials and methods

The trial was established at Mbalmayo, southern Cameroon (3°51' N, 11°27' E) in 1993, on a Typic Kandiudult, manually cleared from secondary forest in 1991. Average annual rainfall is 1513 mm with a bimodal distribution: mid-March to mid July and September to mid-November. The trial was a randomized complete block design, with 5 fuel loads (FL) (10 [no-burn] 10, 1000, 3000 and 5000 Mg ha^{-1} of wood) and 4 replicates. The 10 Mg ha^{-1} represent 2 years natural re-growth. The other FLs represent boles of 16 to 127 cm Ø at wood densities of 0.5 to 0.8 Mg m^{-3}. Wood was weighed and stacked on 6 x 6 m plots and ignited at 13:00h on 23 August. Temperatures were determined with heat sensitive crayons, melting at 52, 101, 149, 204, 253, 316, 399, 510, 593, 704, and 788°C. Crayons were placed between metal sheets and placed on the soil surface and at 5, 10, 20 and 30 cm depth. Below ground sheets were horizontally inserted in the sidewalls of three narrow holes per plot. Holes were refilled and compacted. At 24 hours after ignition, the soil temperature was measured at 0, 3, 5, 10 and 12 cm depth in five locations per plot with a hand held thermometer. Soil organic C, total N, exchangeable Ca, Mg and K was determined before the burn in 10 cm increments to 50 cm depth. No differences between plots were found. After burning, soil pH was determined in a 2:5 soil to water ratio at 0-5, 5-10, 10-15, 15-20, 20-30, 30-40, and 40-50 cm depths, at 9, 23, 37, 51, 65 and 79 DAB. Maize cv. CMS 8704, (100 days from emergence to harvest) was planted on 31 August 1993, 7 DAB and on 21 April 1994 at 6.67 plants m^{-2}.

Results and Discussion

Burning 10 Mg ha^{-1}did not exceed 52°C at the soil surface. During the burn of 1000, 3000 and 5000 Mg ha^{-1} wood, the mean temperature at the soil surface reached 770°C and 214°C at 5 cm depth, without differences between FLs (Figure 1). In some cases temperatures at the soil surface exceeded 788°C. At 10 cm depth the soil temperature was lower (133°C) under 1000 Mg ha^{-1} FL than under 3000 Mg ha^{-1} (173°C, $p<0.04$) and under 5000 Mg ha^{-1} (208°C, $p<0.003$). At 20 cm depth the temperature under 5000 Mg ha^{-1} FL reached 163°C, which was significantly higher than under 1000 Mg ha^{-1} FL (52°C, $p<0.003$) and under 3000 Mg ha^{-1} (105°C, $p<0.04$). In 3000 and 5000 Mg ha^{-1} FL temperatures reached >52°C at a depth of 30 cm, without significant differences between FLs. Twenty-four hours after ignition, the soil temperature at the surface was not different between the 10 and 1000 Mg ha^{-1} FL but significantly lower than under 3000 and 5000 Mg ha^{-1} FL. In all deeper layers all FLs were significantly different from each other (Figure 1). At the soil surface, the temperature under 5000 Mg ha^{-1} FL exceeded 150°C.

Between burning and the last pH determination a total of 733.6 mm of rain fell. The no-burn and the 10 Mg ha^{-1} FL had the same soil pH at all depth throughout the sampling period (Figure 2). In 40-50 cm depths, pH did not change. Compared with no-burn and 10 Mg ha^{-1} FL, pH increased significantly at 1000 Mg ha^{-1} FL to 15 cm depth, and at 3000 and 5000 Mg ha^{-1} FL to 40 cm depth after. At 9 DAB, after 37 mm of rain, soil pH had increased significantly between 0 and 15 cm depths, at 5000, 3000 and 1000 Mg ha^{-1} FL. At 23 DAB, soil pH at 1000 Mg ha^{-1} FL was significantly lower than at FLs of 5000 and 3000 Mg ha^{-1}. Soil pH at 1000 Mg ha^{-1} FL remained for most of the sampling period at intermediate values between no-burn and 10 Mg ha^{-1} FL and 5000 and 3000 Mg ha^{-1} FL.

Burning large amounts of biomass reduced maize grain yield and total biomass yield significantly through a reduced plant density, fewer cobs m^{-2} and a lower grain mass in the first season after burning (Table 1). Maize grain yield and total biomass production was inversely correlated with the sum of temperatures (yield=19.2 – 0.0121 Temperature Sum, $r^2=0.61$ $p<0.05$) attained throughout the monitored soil profile. Cropping maize for a second season had reverse, yet insignificant yield responses, with highest yields in plots where large amounts of wood were burned.

Table 1: Maize yield components of the first crop (December 1993) and after a second crop (August 1994) after burning large amounts of biomass on an Ultisol in southern Cameroon.

December 1993	Fuel load	Plants m^{-2}	Cobs m^{-2}	Marktable cobs m^{-2}	Grain DM ($Mg\ ha^{-1}$)
	No - burn	5.32 a	5.32 a	2.13 a	2.15 a
	10 $Mg\ ha^{-1}$	5.51 a	5.23 a	2.13 a	2.43 a
	1000 $Mg\ ha^{-1}$	5.14 a	3.89 b	1.67 b	1.56 b
	3000 $Mg\ ha^{-1}$	2.50 b	1.48 c	0.51 c	0.33 c
	5000 $Mg\ ha^{-1}$	1.99 b	1.57 c	0.55 bc	0.50 c
August 1994	Fuel load	Plants m^{-2}	Cobs m^{-2}	Marketable cobs m^{-2}	Grain DM ($Mg\ ha^{-1}$)
	No - burn	6.17	6.39	1.89	2.09
	10 $Mg\ ha^{-1}$	5.62	5.51	2.75	3.02
	1000 $Mg\ ha^{-1}$	6.06	4.95	2.50	2.73
	3000 $Mg\ ha^{-1}$	5.77	6.11	3.22	4.05
	5000 $Mg\ ha^{-1}$	6.05	6.00	2.00	3.57

Figures within columns, followed by the same letter are not significantly different at $p<0.05$.

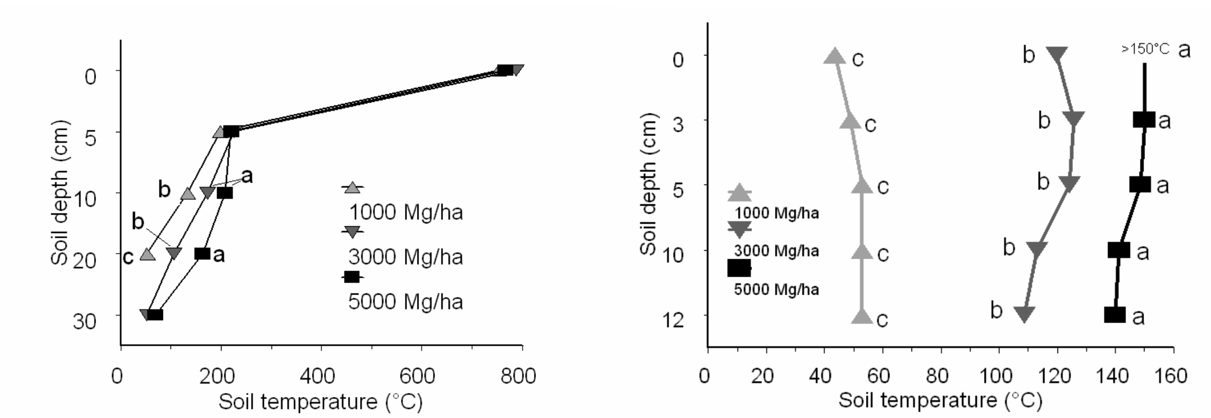

Figure 1: Soil temperature during (left) and 24 hours after ignition of large amounts of biomass on a Cameroonian Ultisol. Within the same soil depth, values labeled with the same letter are not significantly different at $p<0.05$.

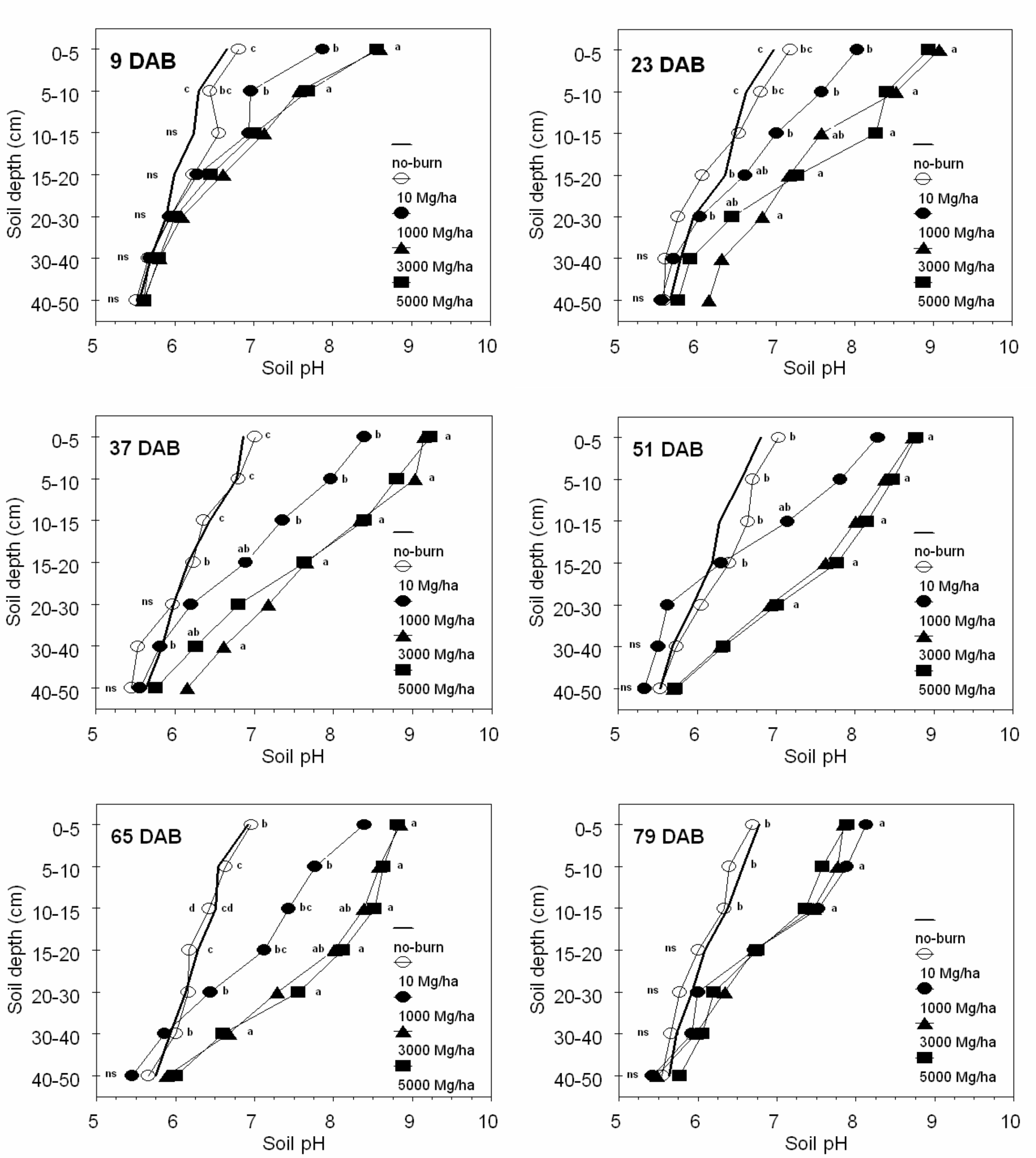

Figure 2: Soil pH between 9 and 79 days after burning large amounts of wood on an Ultisol, Mbalmayo, southern Cameroon, 1993. Within the same soil depth, values labeled with the same letter are not significantly different at p<0.05.