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Effect of Pine Plantation Surface fires on Soil Chemical Properties in Uganda

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Abstract

Population growth has increased demand for forest products, but supplies from natural forests have reduced due to degradation. Tree plantations have been established. However, plantation forestry in Uganda is greatly affected by the recurrent fires. Few studies on impact of fires on soil chemical properties have been done in Uganda. Research was carried out in Hoima District at Corewoods Limited to; i. compare soil pH in burnt and un-burnt plots, ii. compare the exchangeable bases (K, Mg, and Ca) in burnt and un-burnt plots, iii. to compare nitrogen, available phosphorus and soil organic matter in burnt and un-burnt plots. Diagonal sampling was used in both burnt and un-burnt areas where 6 plots each consisting of 5 sub-plots were made. Thirty (30) composite soil samples were collected from each area, giving a total of 60 for soil chemical analysis. Nitrogen, soil organic matter content, soil pH and exchangeable cations were determined using standard laboratory procedure. Data was analyzed using Mintab14 and the T-test was used for comparisons. Results showed a significant increase in soil pH in burnt plots (P value = 0.024), but no significant change in organic matter (P value = 0.077) and available phosphorus (P value = 0.77). Total nitrogen was significantly different (P value = 0.013). There were significant differences in exchangeable bases (Ca, Mg and K) in burnt and un-burnt plots with P values 0.018, 0.034 and 0.001 respectively. Due to the effect of fires on soil chemical properties, plantation managers should be fully equipped; and prescribed burning as management tool should be put on the discussion platform such that better techniques and skills are employed.

Keywords: Plantation fires, pine, soil, soil surface.

Introduction

Forest fires are an important disturbance in most forest ecosystems affecting the vegetation, soils and nutrient cycles[1]. The impacts depend on the fire severities and the type of fire[2]. Fire types can be classified according to the location, source, and behavior. Forest fires can be crown fires, ground fires and surface fires. In Uganda, surface fires are the most common in natural forests and plantations, with a potential of wiping out entire investments. Fires may be accidental or set by individuals with bad motives. Surface fires impose a wide range of effects on vegetation, wildlife, water resources of watersheds and soils. Plantation soils are the most important aspect, since soils provide the medium for plant growth and supply plants with essential nutrients for growth.

Prescribed burning has been one of the management tools used in pine plantations for instance pine species such as the "canary island pine" do sprout after forest fire[3]. In addition, the increasing wildfires coupled with fire free intervals of several years to allow re-establishment has led many foresters to advocate for the exclusion of fire from the woods. However, the low costs and easy use of fire as a management tool in plantations is common and is likely to continue due to the ease of implementation but fire can significantly affect some physical, biological and chemical properties[4,5]. Fire whether wild or prescribed may be a threat to pine plantation management depending on its intensity. Low intensity prescribed fires may have little adverse effects on soil properties and in fact may improve soil nutrient availability, but high intensity fires may alter the soil properties in the long run[6,7]. Generally, studies show that the resulting post fire conditions alter the soil aggregate stability and water infiltration[8]. Fires also alter biomass productivity, species recruitment, microbial composition and carbon sequestration potential[9].

In Uganda, degradation of natural forests has reduced their potential to meet the current and future timber and wood fuel demand. Consequently, there has been a large shift to plantation forestry, with pine species such as *Pinus caribea, Pinus orcarpa, Pinus patula* recommended. However, the fires whether prescribed or wild have affected pine plantation management and investments in Uganda, with at times complete losses. A study was carried out at one of the plantations that had been affected by fire. The objectives were to i. compare soil pH in burnt and un-burnt plots ii. compare the levels of exchangeable bases (potassium, calcium, and magnesium) in burnt and un-burnt plots and iii. compare the levels of nitrogen, phosphorus and soil organic matter in burnt and un-burnt plots of the pine plantation. We assumed that pine trees have no significant effect on the soil nutrient supply or had the same effects in both burnt and un-burnt plots before the fire; and that burnt or un-burnt areas selected were geographically proximate to make meaningful comparisons.

Material and Methods

Study area: The study was carried out at Corewoods Company, which is located in Hoima District, western Uganda (1°32'N and 31°12'E). Figure 1 shows the location of Hoima district. The plantation site is located in the former Bujawe Central forest reserve covering block 32 and 33 and lies at altitude of 1,108 meters above sea level. The reserve is owned by the National Forestry Authority (NFA) on behalf of the government and the people of Uganda. It lies along Buseruka road, 21km from Hoima town towards the oil fields near Lake Albert. It occupies a total of 550ha with an additional 50ha of natural conservation belts that include wetlands and biological sensitive strips. Daily temperatures vary between 11 and 32°C[10]. The area receives an average annual rainfall of 1250−1500mm with two peaks, March−May and August−November. Generally the soils are deep, loamy and dark grey in colour. The slope ranges between 5−10%. Previously the area was covered with trees such as *Albizia coriaria*, *Celtis durandii*, and *Alstonia boonei* and also grass species like *Hyparrhenia rufa*, and *Pennisterm purpureum*. Wetlands and valley bottoms have *Imperata cylindrica*, *Panicum maximum* and sedges in addition to other herbs. Replanting in the reserve was done to restore the vegetation cover, prevent further degradation and to minimize the expenses associated with managing a degraded area. Farming of trees at the reserve commenced in September 2006 and only commercial tree species were planted including; *Araucaria* spp., *Eucalyptus grandis*, *Eucalyptus* clones, *Pinus caribeae caribeae* (PCC) and *Pinus caribeae var hondarensis* (PCH). The area was compartmentalized basing on tree species and age for effective management and thecompartments include 1A, 1B, 2A, 2B, 2C, 3A, 3B, W1, W2, G2, J, I, H and the unknown. The study was carried out in compartment 2A which is 28ha, with 15ha burnt and 13ha un-burnt. The trees in compartment 2A were planted in 2007 and got burnt in September 2011.However, the intensity of fire was moderate because the trees did not get completely burn and there was no replanting done.

Research design: The study was conducted on twelve square plots of (50x50)m,6 plots in burnt area of compartment 2A and the other 6 in un burnt area in the same compartment arranged along a diagonal to capture the effect of slope. A meter tape and rules of trigonometry were used to ensure straight dimensions. Each (50x50) m plot was sub-divided into five (5x5) m square sub-plots, four towards the corners and one in the centre. There was also an interval of 50m between each (50x50) m square plot.

Soil sampling preparation and analysis: From each (5×5) meter plot, 5 samples of soil were collected at a depth of 0−20cm using an auger from 4 spots towards the corners and one spot at the centre. The soils from each sub-plot were mixed thoroughly and quartered to obtain a composite sample which was put in black polythene, and labelled. The total number of samples collected from burnt area was 30 (6×5) and the same was done for the burnt area, giving a total of 60soil samples. Soil samples were oven dried at 40−50°C for two days, ground and sieved to (<2mm). Soil pH was determined using de-ionised water. Soil organic matter was determined by the Walkley-Black method. Total N was determined by Kjeldahl oxidation and semi-micro Kjeldahl distillation[11]. Available P was determined using Bray 1 method. Exchangeable Ca, Mg and K were extracted using the Mehlich-3 method[12]. K was determined using a flame photometer and the other bases by atomic absorption spectrometry[13].

Data analysis: Comparisons of the soil chemical properties between the un-burnt and the burnt plots were made using the two-sample t-test to test for difference in the means using statistics package Minitab 14.A level of significance p=0.05 was used.

Results and Discussion

Soil pH: Table 1 shows that the mean soil pH value for the burnt plots was 5.940 (range 4.7−6.9) and for the un-burnt plots 5.657 (range 4.3−6.4). The means were significantly different (P value = 0.024). Generally, the soils were found to be slightly acidic to moderately acidic in nature (overall range 4.3−6.9). In general, the soil pH values are within the range for *Pinus caribaea* that generally grows well on moderately acid soils (pH 3.5−6.0) and very poorly on alkaline soils[14]. According to the results, soil pH increased from a mean value of 5.657 in un-burnt plots to 5.940 in burnt soils, implying that burning caused an increase in soil pH. This increase may be attributed to ash accretion because during burning certain cations (Ca, Mg, K, and Na) become available and then bond to soil organic matter and thus increase the soil PH. The magnitude and duration of change is dependent on the amount and base content of the ash, the texture and organic matter content of the soil[15]. The increase was significant because the degree of impact is typically dependant on the soil organic matter content,which is fairly high and the amount of ash which is determined by fuel load meaning that the area was covered with sufficient fuel load prior to burning[16,17].

Table-1
Soil pH, organic matter, extractable phosphorus and total nitrogen measured in burnt and un-burnt plots in a pine plantation in Hoima district, Uganda

Soil chemical property	Burnt			Un-Burnt			P-value
	Mean	Range	St.Dev.	Mean	Range	St.Dev.	
Soil pH	5.94	4.7–6.9	0.401	5.66	4.3–6.4	0.536	0.024
Soil organic matter (%)	4.59	2.6–6.1	0.917	5.11	2.8–8.2	1.29	0.077
Extractable phosphorus (mg kg^{-1})	5.77	1.1–29.6	7.24	6.34	1.2–39.2	7.98	0.77
Total nitrogen (%)	0.172	0.1–0.2	0.03	0.188	0.16–0.22	0.0152	0.013

Available Phosphorus: The mean value for available phosphorus was 5.77 mg kg^{-1} (range 1.1–29.6 mg kg^{-1}) for burnt plots and for un-burnt plots, the mean value was 6.34 mg kg^{-1}(range 1.2–39.2 mg kg^{-1}). There was no significant difference between the means (P value = 0.77). The mean value of extractable phosphorus in burnt plots was lower than in the un-burnt plots meaning that available phosphorus decreased due to oxidation[18] and loss as particulates in smoke[19]. In another study, a high intensity wildfire resulted in an immediate increase in phosphorus levels[16]. Usually, a large portion of the nutrient reserve in most forest ecosystems is contained in the organic material on the forest floor and on burning releases nutrients[20]. The fire that occurred at Corewoods consumed the vast majority of organic matter on the forest floor, although areas of light burn did occur on the margins of the fire and within the burnt region. Measuring fire behaviour (e.g., intensity, duration, rate of spread) is often problematic. However, judging by the percentage of trees consumed by the fire, the incomplete consumption of the trees in compartment 2A and no need for re-planting, we conclude that the fire was of moderate intensity. While fire can eliminate a large portion of the organic material in the litter layer, it speeds up the process of oxidation and can result in readily available nutrients in the ash. Following a precipitation event, these nutrients can dissolve and enter the soil. In this study, lower available P values may also be attributed to ash removal from the site by wind or surface runoff since the field was located to sloping land.

Soil organic matter: Table 1 shows that the mean soil organic matter content for the burnt plots was 4.593 % (range 2.6–6.1%) and for the unburnt plots 5.11% (range 2.8–8.2%). However, there was no significant difference between the means(P value = 0.077). For good Pine growth, the SOM level in the mineral top soil must be 3–5%[21]. Results showed that mean soil organic matter content in the burnt plots was lower than that of the un-burnt plots, implying that burning decreased the organic matter content. This reduction may be attributed to oxidation of organic carbon that is close to the soil surface[20]. However, the insignificant reduction may be because the fire intensity was moderate due to probably the quantity of litter on the ground. However, an increase in mineral soil organic matter content following fire has been reported, but the levels obtained decreased to pre-fire conditions within a year after burning[22]. In this study, despite the moderate intensity, the fire probably consumed the O-horizon or part of it leading to a reduction in soil organic matter.

Total Nitrogen: Mean total nitrogen content in the burnt plots was 0.1725% (range 0.1–0.2%) and the un-burnt soils the mean value for total nitrogen content was 0.1877% (0.16–0.22%). Results showed a significant decrease in the amount of total soil nitrogen in burnt soils compared to un-burnt soils, which is attributed to the loss through volatilization[23]. The reduction in soil nitrogen content in forest ecosystems has been reported in other parts of the world [24]. The observed reduction may also have been due to increased leaching of NO_3^- during the rainy season since the data was collected within the rainy season. Consumption of the litter layer during fire leads to increased infiltration rates for burned soils in rainy season, in turn, could lead to increased leaching of nitrogen in the form of NO_3^-.

Exchangeable cations (Ca, Mg and K): Average calcium content in the burnt plots was 5.91meq/100g (range 0.9–10.1meq/100g) and 7.33 meq/100g (range 2.1–12.5 meq/100g) for the un-burnt plots as shown in table 2. The means for the burnt and un-burnt plots were significantly different (P value=0.018) (table 2). The mean magnesium content in the burnt plots was 2.314 meq/100g (range 0.58–3.64meq/100g) and the un-burnt plots 2.847meq/100g (range 1.02–4.97meq/100g). The means were significantly different (P value=0.034). There was a significant difference observed in the soilpotassium content (P value=0.001). Mean potassium content in burnt plots was 0.522meq/100g (0.1–1.1meq/100g) and for the unburnt plots 0.787meq/100g (0.2–1.2meq/100g).

Calcium, Potassium and Magnesium were seen to decrease significantly after fire[2,25,22]. The decrease in exchangeable bases (Ca, Mg, K) may have been as a result of ash transport, leaching and erosion[19]. However, higher levels of exchangeable potassium in burned forests for a period of 21 months following a wildfire have been reported[16]. Other results have showed that the amount of Ca and Mg can either increase or remain unaffected as a result of burning[26].

Conclusion

Fire significantly increased the soil pH in burnt soils which was in line with most of the findings of various researchers. However, the magnitude of the increase largely depends on the fuel load and the amount ash generated. Such a change can increase the availability of nutrients such phosphorus, whose availability depends on the soil pH.

Fire significantly decreased the amounts of exchangeable bases (potassium, calcium and magnesium) in the soil. This may impact on tree growth. However, other researchers have reported an increase in soil exchangeable potassium, calcium and magnesium in pine plantations after fire. The reductions obtained in this study may need to be investigated further.

Fire resulted in a significant decrease in soil nitrogen; whereas the decreases in available phosphorus and soil organic matter were insignificant. Nitrogen and phosphorus do play crucial roles in plant physiology and bio-chemistry, and thus reductions may affect tree growth. Soil organic matter plays a vital role as a source of nutrients, in addition to improving other soil physical and chemical properties, reductions may reduce tree growth. However, trees extracting nutrients from deeper layers and later depositing litter and vegetation growing and decaying in the plantation, may help increase nitrogen, available phosphorus and soil organic matter in successive years.

Table-2
Exchangeable calcium, magnesium and potassium measured in burnt and un-burnt plots in a pine plantation in Hoima district, Uganda

Exchangeable base	Burnt			Un-Burnt			P-value
	Mean	Range	St.Dev.	Mean	Range	St.Dev.	
Calcium (meq/100g)	5.91	0.9–10.1	2.45	7.33	2.1–12.5	2.05	0.018
Magnesium (meq/100g)	2.314	0.58–3.64	0.952	2.847	1.02–4.97	0.949	0.034
Potassium (meq/100g)	0.522	0.1–1.1	0.237	0.787	0.2–1.2	0.324	0.001

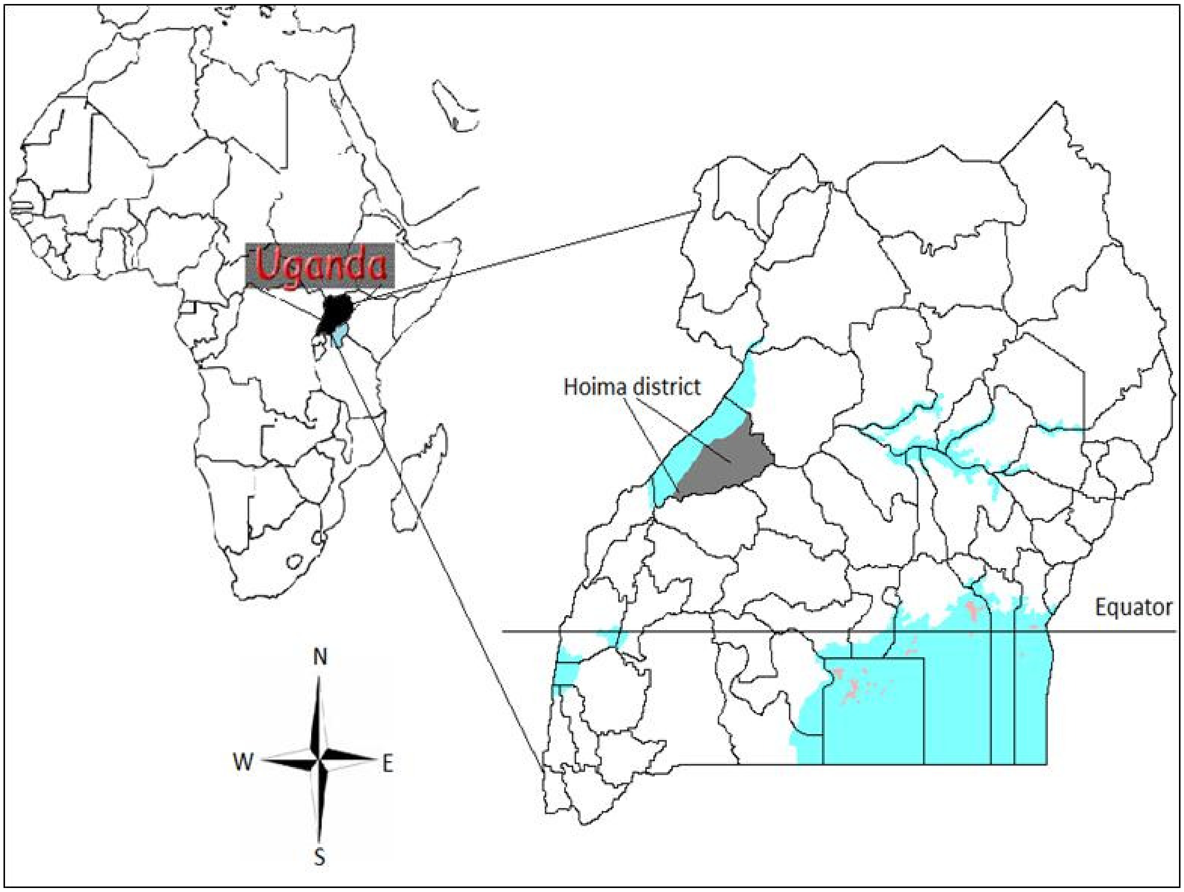

Figure-1
Map of Africa showing Uganda and map of Uganda showing the location of Hoima district, western Uganda

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References

1. Schmidt M.W.I., Skjemstad J.O., Gehrt E. and Kogel-Knabner I., Charred organic carbon in German chernozemic soils, *Eur J Soil Sci.,* **50**, 351–365 **(1999)**
2. Neary D.G., Klopatek C.C., Debano L.F., and Folliott P.F., Fire effects on belowground sustainability: a review and synthesis, *Forest Ecol Manag,* **122**, 51-71 **(1999)**
3. Farjon A. Pines, 2nd edition 2005, *E.J. Brill, Leiden,* ISBN 90-04-13916-8 **(1984)**
4. Kutiel P. and Shaviv A., Effects of soil type, plant composition and leaching on soilnutrients following a simulated forest fire, *Forest Ecol Manag,* **53**, 329-343 **(1992)**
5. Lavoie M., Starr G., Mack M.C., Martin T.A. and Gholz H.L., Effects of a prescribed fire on understory vegetation, carbon pools, and soil nutrients in a longleaf pine-slash pine forest in Florida, USA, *Natural Areas J.,* **30**, 82-94 **(2010)**

6. DeBano L.F., The effect of forest fire on soil properties. Symposium on Management and Productivity of Western-Montane Forest Soil, 151-156, Boise, ID, USA **(1990)**

7. Certini G., Effect of fire on properties of soil - A review, *Oecol,* **143**, 1-10 **(2005)**

8. Mataix-Solera J. and Doerr S.H., Hydrophobicity and aggregate stability in calcareous top soils from fire-affected pine forests in southeastern Spain, *Geoderma,* **118**, 77–88 **(2004)**

9. Alward R.D., Detling J.K. and Milchunas D.G., Grassland vegetation changes and nocturnal global warming, *Science,* **283**, 229–231 **(1999)**

10. Howard P.C., Nature Conservation in Uganda's Tropical Forest Reserves, IUCN, Gland, Switzerland **(1991**)

11. Bremner J.M., Determination of nitrogen in soil by the Kjeldahl method, *J. Agric. Sci.,* **55**, 11–33 **(1960)**

12. Mehlich A., Mehlich-3 soil test extractant: A modification of Mehlich-2 extractant, Comm., *Soil Sci. Plant Anal.,* **15**, 1409–1416 **(1984)**

13. Okalebo J.K., Gathua K.W., Woomer P.L., Laboratory Methods of Soil and Plant Analysis: A Working Manual. Second edition. SACRED-Africa, Nairobi, Kenya **(2002)**

14. Nieto V.M. and Rodriguez J.,Species discrimination: In tropical tree seed manual; Corporacion Nacional de investigación of Santaf'e de Bogote Colombia **(2003)**

15. Pritchett W. and Fisher R., Properties and management of forest soil. Second edition, John Wiley and Sons, Inc., New York, New York, USA, 494 **(1987)**

16. De Ronde C., Impact of prescribed fire on soil properties: comparison with wildfire effects. In: Goldammer JG & MJ Jenkins (eds); Fire in ecosystem dynamics: Mediterranean and northern Perspectives: 127-136 **(1990)**

17. Diaz-fierros F., Benito E., Vega J.A., Castelao A., Soto B., Perez R. and Taboada T. Solute loss and soil erosion in burnt soil from Galicia (NW Spain). In: Goldammer, J.G.& Jenkins, M.J. (eds). Fire in ecosystem dynamics: Mediterranean and northern perspectives: 103-116, SPB Academic Publishing, The Hague, The Netherlands **(1990)**

18. Raison R.J., Khanna P.K. and Woods P.V., Mechanisms of element transfer to the atmosphere during vegetation fires. *Can J For Res.,* **15**, 132-140 **(1985)**

19. Macadam A.M., Effects of broadcast slash burning on fuels and soil chemical properties in the sub-boreal spruce zone of central British Columbia, *Can J For Res.,* **17**, 1577–1584 **(1987)**

20. Wagner G.H. and Wolf D.C., Carbon transformations and soil organic matter formation. In: Sylvia, D.M., Fuhrmann, J.J., Hartel, P.G.and Zuberer, D.A. (eds). Principles and applications of soil microbiology: 218-258 **(1998)**

21. Behari J., Microwave dielectric behavior of wet soils: *remote sensing and digital image processing,* Springer, New Delhi India, 164 **(2005)**

22. Trabaud I., The effects of different fire regimes on soil nutrient levels in *Quercus coccifera* garrigue. In: Kruger, F.J., Mitchell, D.T.and Jarvis, J.U.M. (eds) Mediterranean-type ecosystems: the role of nutrients: 235-243, Springer-Verlag, New York, USA **(1983)**

23. DeBano L.F., Neary D.G. and Ffolliott P.F., Fire's Effects on Ecosystems, New York: John Wiley & Sons, Inc. **(1998)**

24. Wan S., Dafeng H. and Luo Y., Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis, *Ecol Applic,* **11**, 1349-1365 **(2001)**

25. McKee W.H., Changes in soil fertility following prescribed burning on coastal plain pine sites, Asheville, NC: 23 **(1982)**

26. Campbell R.E., Baker M.B. and Ffolliott P.F., Wildfire effects on a ponderosa pine ecosystem: An Arizona case study. USDA Forest Service Research Paper RM-191 **(1977)**