JMHT Vol. XV, (3): 91–95, Desember 2009 Artikel Ilmiah
ISSN: 2087-0469

Effect of Charcoal Earth Kilns Construction and Firing on Soil Chemical Characteristics

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Abstract

Assessments of localized ecological and environmental impacts of charcoal production including effects on soils at kiln sites is seldom undertaken, with more emphasis being placed on the global effects of the practice such as forest degradation and deforestation. A study was undertaken in Narok, Eldoret, Moiben, and Turbo in Kenya on known charcoaling sites to investigate the impact of charcoal production on the soil chemical characteristics. Composite soil samples from 12 sampling points for all study sites were taken randomly at a depth of 0–15 cm. The samples were conditioned and analyzed for pH, particle size, Cation Exchange Capacity (CEC), extractable phosphorus, organic carbon, nitrogen, and exchangeable bases. A comparison of the soil properties between undisturbed sites and charcoaling sites showed significant differences for all chemical properties except CEC, Mg, and K. For the Moiben site, only the pH showed no significant difference ($p < 0.05$). The observed high carbon content reduced with time for the one year following charcoaling activity and was attributed to soil erosion since charcoal production activities reduced the sites vegetation cover. Most chemical changes positively enhanced the nutrients content and availability, but were short lived probably due to soil erosion. These results demonstrate the need to adopt technologies with minimum impact on the soil, or a shift to centralized production sites outside forest ecosystems or farmlands.

Keywords: charcoal, earth kilns, soil chemical properties, erosion

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Introduction

Charcoal, with a national mean utilization rate of 47% of households, representing 82% and 34% of urban and rural households respectively, occupies a unique position in the region's energy mix, being used by both low and high income groups (Kituyi 2002; MoE 2002; Kituyi *et al.* 2001; Senelwa & Hall 1993; Nyoike & Okech 1992; O'Keefe *et al.* 1984). The use of charcoal in average-sized towns and rural areas in Africa is becoming increasingly evident. Indeed, the charcoal sector has acquired considerable economic weight because of increasing urbanization, sometimes accounting for an annual turnover of several million dollars for a number of African countries (Girard 2002). In Kenya for instance, the total annual charcoal production and consumption is estimated at 1.6–2.4 million tonnes, in a KShs23–32 billion (US$0.32–0.45 billion) industry, (EAA 2003; ESDA 2005). About a quarter of household income in Kenya is spent on wood fuel, usually regarded as the poor person's energy source, since alternative energy sources including kerosene and liquefied petroleum gas (LPG) are beyond the means of most Kenyans (Kituyi 2002).

Recent investigations by Glaser *et al.* (2001) showed that carbonized materials from the incomplete combustion of organic material are responsible for maintaining high levels of soil organic matter and available nutrients in anthropogenic soils. During burning of the above-ground biomass, the nutrients are rapidly released into the soil. These nutrient additions have positive effects on soil fertility only for a short period (Kleinman *et al.* 1995). Chidumayo (1994) reported that the process of charcoal making might increase soil *pH* by up to 2 units; mineral phosphorous may more than double while other nutrients do not significantly change. Charcoal may not only change soil chemical properties, but also affect soil physical properties such as soil water retention and aggregation (Piccolo & Mbagwu 1990; Piccolo *et al.* 1996).

Almost 100% of Kenya's charcoal, and indeed for the entire East African region is produced using earth kilns, characterised by poor operation practices e.g. poor loading, use of green wood, poor control, and premature harvesting of charcoal before full carbonisation (Senelwa *et al.* 2006). As a result, the processes are very inefficient with typical efficiencies in the range of 10–15% (MoE 2002). Traditional carbonisation methods consist of either pit kilns or earth mound kilns (ILO 1988). These kilns are cheap and simple to construct where the raw material is located, involve no relocation cost, and require low capital investment for the operators (MoE 2002). Despite these advantages, they are considered to be very wasteful.

Very few studies have been undertaken in Eastern Africa to assess the ecological or environmental impacts associated with charcoal production. For instance, the extent of devegetation, forest degradation, and deforestation in Kenya due to inefficient charcoal production and utilization technologies is not known. Similarly, the effects of earth kiln construction and firing on soil properties has not been investigated. This study therefore investigated the impact of charcoal production using earth kilns on soil chemical characteristics.

Method

The study was based in Uasin Gishu and Narok Districts in Rift Valley Province in Kenya. Uasin Gishu District is a highland plateau located between longitudes 34°50' and 0°37' E and latitudes 0°03' and 0°55' N and has a total area of 3327.8 km^2. Altitudes fall gently from 2700 m at Timboroa in the East to 1500 m at Kipkaren in the West. The district has an average annual rainfall ranging between 900–1200 mm. The rains occur between March and September, with 2 distinct peaks in May and August. Temperatures range between 18–26 °C. The major soil types include red loam, red clay, brown clay, and brown loam. Overall, the main energy source in the whole district is firewood (84.1%) and charcoal (9.7%). Paraffin comes a distant third with 5.35% of the population using it and others including electricity, LPG and solar in different forms such as photovoltaic systems (PVs) coming with a paltry 0.9% (RoK 2002a).

Narok District is situated in the southern part of the Rift Valley Province. It lies between latitudes 0°50' and 2°05' S and longitudes 35°58' and 36°0' E and occupies a total area of 15,087.8 km^2**.** The temperatures range from 5 °C in July to 28 °C in November to February. The area has poor quality soils and rains are unreliable. Almost 100% of the population used firewood and/or charcoal for cooking. About 70% used kerosene for lighting, 2% had PV systems while 2% used LPG.

The experiment employed simple random sampling method, in which composite soil samples from 12 sampling points in Eldoret, Moiben, Turbo, Kapsaret in Uasin Gishu and Nkareta and Nkoben in Narok were taken randomly at a depth of 0–15 cm. The samples were conditioned and analyzed for *pH*, particle size, Cation Exchange Capacity (*CEC*), extractable phosphorus (*P*), organic carbon (*C*), nitrogen (*N*), and exchangeable bases. The soil was air-dried and sieved through a 2 mm sieve. Soil *pH* was determined by the water method (1:2.5 for soil:water). Particle size analysis was done by hydrometer method, while exchangeable acidity was undertaken by Walkely-Black method (Okalebo *et al.* 2002). The *CEC* was done using Kjedhal distillation and exchangeable cations determined using atomic absorption spectrometry (Okalebo *et al.* 2002). Extractable Olsen *P* was determined after extraction with 0.5M $NaHCO_3$ followed by colorometric determination of *P* (Okalebo *et al.* 2002).

For each site, sampling was undertaken at four different times (before the site was disturbed), i.e. before charcoaling activities, immediately after charcoal production, six months following charcoal production, and one year after charcoal production. Comparisons were made over time, and between the different sites.

Result and Discussion

Results for soil chemical analysis for Moiben (Table 1) showed that there were significant differences between the treatments for all the chemicals except *pH*. After DMRT, results showed that *C*, *CEC*, magnesium (*Mg*), potassium (*K*), and *P* were significantly affected by the charcoal production ($p < 0.05$). Although calcium (*Ca*) and nitrogen (*N*) treatments were significantly different, the differences in the undisturbed sites and the fresh kilning sites were more after some time. Although there were apparent variations in the *pH* between the treatments, they were not significant (p value ≤ 0.05).

In Turbo there were significant differences between the treatments for all the chemicals except *K* (Table 2). Soil *pH*, *C*, *Ca*, *N*, and *P* were significantly affected by the charcoal production activities ($p < 0.05$). However, while *CEC* and *Mg* were significantly different, there were no differences between the undisturbed site and the freshly used sites.

In Eldoret there were significant differences between the treatments for all the chemicals except *Mg*, *CEC*, and *K* (Table 3). As observed in Moiben and Turbo, *pH*, *C*, *N*, and

Table 1 Soil chemical characteristics for Moiben kiln site

Treatment	*pH*	*CEC* (me 100g^{-1})	*C* (%)	*Mg* (me 100g^{-1})	*K* (mg kg^{-1})	*Ca* (me 100g^{-1})	%*N*	%*P*
Undisturbed	6.18	7.6^a	3.21^a	15^a	32.5^a	59.8^{ab}	0.208^b	0.043^a
Fresh kiln site	7.25	18.7^a	9.03^c	28^b	80^b	58.7^{ab}	0.270^c	0.083^c
After 6 months	6.67	12.8^{ab}	7.05b^c	23.5^b	47.5^a	76^b	0.114^a	0.124^d
After 1 year	6.37	6.3^c	5.67^b	11.1^a	25^a	33.5^a	0.113^a	0.073^b

Note: for any characteristic, values with the same letter in each column are not significantly different from each other.

P were significantly affected by the charcoal production activities on this site ($p < 0.05$). Whereas *Ca* was significantly different, there were no differences between the undisturbed sites and the freshly used sites.

Results for soil chemical analysis for Narok (Table 4) showed that there were significant differences between the treatments for all the chemicals except *CEC*, *Mg*, and *K*. Similarly, *pH*, *C*, and *Ca* were significantly affected by the charcoal production activities on this site ($p < 0.05$). Whereas *N* and *P* were significantly different, there were no differences between the undisturbed site and the freshly used sites.

The low to moderate *pH* values observed in the soils in the study areas are typical of tropical soils (Sanchez 1976). Kiln operation affected soil chemical properties but the effect seemed to vary with site and therefore with the parent soil characteristics. In Moiben, *CEC*, *Mg*, *K*, and *P* were influenced. In Turbo, *Ca*, *N*, and *Mg* were affected while in Eldoret, only *N* and *P* were affected. In Narok, only *Ca* was affected. Although the productivity of the sites was not investigated *per se*, it would be expected that when the top soil is removed and used to cover a kiln, site productivity of the dug up areas would be reduced, and that such nutrients may take years to replace. During burning of the aboveground biomass the nutrients are rapidly released into the soil. These nutrient additions have positive effects on soil fertility which are however, only short-lived (Kleinman *et al.* 1995).

In addition to the effects on the soil nutrients, there were significant differences in the *pH* values except for Moiben site. This showed that carbonisation at the sites had an effect on the *pH*. The addition of charcoal increased the *pH* of soils with various textures by up to 1.2 *pH* units from *pH* 5.4–6.6 (Mbagwu & Piccolo 1997). In similar studies elsewhere, this effect was still detectable 3 years after charcoal application where the *pH* values were 5.8 and 6.3 in the control and the charcoal plots respectively (Kishimoto & Sugiura 1985).

Another similar trend observed in all the sites was the low levels of *C* in the undisturbed sites than the sites where earth kilns had been operated (Table1, Table 2, Table 3, and Table 4). This clearly showed that charcoal production on any one site increased the *C* content of the soil on that particular site. However, this *C* content reduced with time

Table 2 Soil chemical characteristics for Turbo kiln site

Treatment	*pH*	*CEC* (me $100g^{-1}$)	*C* (%)	*Mg* (me $100g^{-1}$)	*K* (mg kg^{-1})	*Ca* (me $100g^{-1}$)	*%N*	*%P*
Undisturbed	4.55^{a}	29.4^{ab}	2.53^{a}	17.5^{bc}	17.5	25.4^{a}	0.067^{a}	0.026^{a}
Fresh kiln site	6.51^{b}	35^{b}	10.38^{c}	21.6^{c}	35	52.3^{b}	0.157^{b}	0.055^{b}
After 6 months	$6.97b^{c}$	20.1^{a}	7.11^{bc}	8.4^{ab}	42.5	69.7^{b}	0.116^{b}	0.042^{c}
After 1 year	7.23^{c}	25.7^{ab}	4.32^{ab}	9^{a}	45	54.8^{b}	0.120^{c}	0.053^{c}

Note: for any characteristic, values with the same letter in each column are not significantly different from each other.

Table 3 Soil chemical characteristics for Eldoret kiln site

Treatment	*pH*	*CEC* (me $100g^{-1}$)	*C* (%)	*Mg* (me $100g^{-1}$)	*K* (mg kg^{-1})	*Ca* (me $100g^{-1}$)	*%N*	*%P*
Undisturbed	4.44^{a}	31.3	1.98^{a}	10.7	40	27.6^{b}	0.140^{a}	0.033^{a}
Fresh kiln site	7.42^{c}	27.9	9.39^{c}	13.3	70	16.9^{a}	0.304^{d}	0.083^{c}
After 6 months	6.10^{b}	33.5	5.58^{b}	19.7	65	27.9^{b}	0.283^{c}	0.091^{d}
After 1 year	6.49^{b}	25.7	2.52^{ab}	14	27.5	23.2^{ab}	0.254^{b}	0.070^{b}

Note: for any characteristic, values with the same letter in each column are not significantly different from each other.

Table 4 Soil chemical characteristics for Narok kiln site

Treatment	*pH*	*CEC* (me $100g^{-1}$)	*C* (%)	*Mg* (me $100g^{-1}$)	*K* (mg kg^{-1})	*Ca* (me $100g^{-1}$)	*% N*	*% P*
Undisturbed	6.76^{a}	13	1.77^{a}	30	37.5	18.9^{a}	0.270^{c}	0.028^{c}
Fresh kiln site	7.34^{b}	21.9	8.4^{b}	22.6	52.5	48.4^{b}	0.141^{a}	0.029^{c}
After 6 months	6.77^{a}	14.3	7.92^{b}	17.9	25	56.4^{b}	0.228^{b}	0.024^{a}
After 1 year	6.65^{a}	24.2	3.24^{a}	22.4	47.5	57.5^{b}	0.280^{d}	0.027^{b}

Note: for any characteristic, values with the same letter in each column are not significantly different from each other.

for the period of one year following the kiln operation probably attributed to soil erosion since *C* loss due to erosion immediately after land clearing is normally alarmingly large.

In all the charcoaling sites there were high levels of soil nutrients as well as exchangeable cations, which may be attributed to the low leaching levels as well as high litter falls. The major recognized avenue for addition of organic matter (and hence nutrients) to the soil from the trees standing on it is through dead and falling leaves, twigs, branches, fruits, and so on (Brinson *et al*. 1980).

Conclusion

The results clearly demonstrate that charcoal earth kiln location and operation has an effect on the soil chemical properties. Although the effects were mostly positive, after some time the nutrients decreased due to soil erosion since the sites were usually left bare.

Recommendation

Since it is desirable to maintain the productivity of soils, it is recommended that charcoal kilns be centralized to reduce the impact on soils. Within such a framework the charcoal would be generated from out side the forests therefore reducing the danger of additional forest destruction. Although this may require costs and labour in transporting the material to the kiln site, the retention of soil productivity outweighs any such negative implications.

Acknowledgement

Part of this work was undertaken as part of the activities under the VICRES funded Project: “Innovation, User Participation and Training to Enhance Earth Kilns Charcoal Production Recoveries in Lake Victoria Basin”. The Financial support is highly acknowledged.

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ISSN: 2087-0469

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