Kiln and wood types affecting charcoal quality: Charcoal use as soil amendments in Northeast Thailand

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ABSTRACT: Charcoal use as soil amendments is attracting research interest. However, charcoals vary in their qualities. It is therefore necessary to seek for appropriate charcoal qualities rendering soil fertility improvement. The purpose of this paper was to classify charcoal qualities produced in Northeast Thailand based on the critical charcoal constituents, i.e., volatile matter, ash, and fixed carbon contents, which regulate soil properties and plant growth. 'Good quality charcoals' for soil amendment should have ash and volatile matter contents in the range of 1.6 -2.8% and 20.4 -35.8%, respectively. This can be achieved by using feedstock of dry woods derived from species similar in quality to eucalyptus and white cedar (krabok) under relatively modern production technique (brick kiln). Knowledge from the results of this paper can be employed to select the good or avoid the bad charcoals as soil amendment.
Keywords: Good and bad quality charcoals; production method; soil conditioner; wood feedstock

Introduction

Organic materials are considered as effective soil amendments for the low fertility soils in Northeast Thailand (Vityakon, 2007). Charcoal is attracting research interests because of its benefits for crop productivity enhancement (Butnan et al., 2015) and global warming mitigation (Butnan et al., 2016). Large amounts of charcoals are produced in Northeast Thailand (Butnan, 2015) pointing out to its potential to be promoted as soil conditioning materials for reducing chemical fertilizer use and costs of crop production.

Variety of feedstock types (e.g., plant species, plant parts, and moisture conditions of feedstock such as fresh or dry woods) and production conditions (e.g., kiln types and producing conditions such as temperature, pressure, and burning duration) are employed to produce charcoal in Thailand (Royal Forest Department, 1985). Divergence of production technology leads to a unique quality of charcoal as reported by Antal and Gronli (2003), that charcoal property is influenced primarily by feedstock, pyrolysis (burning) condition, and interaction of these two factors. The charcoal qualities, in turn, affect crop growth both positively and negatively. To our knowledge, there is no report on observation of appropriate charcoal quality as soil amendment by using diversity of plant species and kiln types traditionally employed in Thailand. Our earlier study reported in Butnan et al. (2015), who showed that a 'good charcoal quality' for corn growth in an acid sandy soil of Northeast Thailand was produced traditionally from eucalyptus wood in a clay kiln

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employing low temperature at about 350°C. By contrast, the charcoal produced under high temperature which its peak up to 800°C decreased the corn growth lower than that in a similar soil without charcoal addition. Charcoal having high volatile matter (VM) content (63.4%) was also a bad one because it led to nitrogen deficiency in corn (Deenik et al., 2011). Of this knowledge, we hypothesized that charcoals having low VM and ash contents would produce a high crop growth. On the contrary, the high VM and ash counterparts yielded the low crop growth. Therefore, objective of the current paper was to classify charcoal qualities appropriate as soil amendment in Northeast Thailand by employing their critical constituents playing a central role in regulation of soil properties and plant growth, i.e., contents of VM, ash, and fixed carbon (fC), compared to those of the based good and bad qualities.

Materials and methods

Data collection

Literature search was performed by emphasizing on proximate values of charcoal, i.e., VM, ash, and fC contents. These charcoal qualities were used because they are prominent factors affecting soil properties and plant growth (Butnan et al., 2015, 2016; Deenik et al., 2010, 2011). Royal Forest Department publications were the main source of published data for the meta-analysis (Royal Forest Department, 1985). The data included charcoals produced from 12 types of wood (Table 1) and 26 types of kilns (Appendix). This was due to limited work in Thailand related to effects of feedstock and kiln types on charcoal qualities (i.e., VM, ash, and fC contents). Local, common, and scientific names of plants used as feedstock for charcoal production are shown in **Table 1**.

Table 1 Local, common, and scientific names of plants used as feedstock for charcoal production.

Local (ไทย) name	Common name	Wood species
A-rang (อะราง)	Yellow batai	*Peltophorum dasyrachis*
Eucalyptus (ยูคาลิปตัส)	Eucalyptus	*Eucalyptus camaldulensis*
Krabok (กระบก)	Wild almond	*Irvingia malayana*
Kao-pod (ข้าวโพด)	Corn	*Zea mays*
Krathin (กระถิน)	Leucaena	*Acacia catechu*
Krathin Na-rong (กระถินณรงค์)	Earleaf acacia	*Acacia auriculiformis*
Krathin Yak (กระถินยักษ์)	Leucaena	*Leuceana leucocephala*
Krian/lian (เกรียน/เลี่ยน)	White cedar	*Melia azedarach*
Ma-kok (มะกอก)	Wild mango	*Spondias pinnata*
Sa-kae (สะแก)	Takeo bushwillow	*Combretum quadrangulare*
Son Pra-di-path (สนประดิพัทธ์)	Casuarina	*Casuarina junghuhniana*
Son Ta-lae (สนทะเล)	She-oak	*Casuarina equisetifolia*

Sources: Pooma and Suddee (2014); Royal Forest Department (1985)

We based the ‘good’ charcoal quality (i.e., 35.8% VM, 2.4% ash, and 61.9% fC) on the results of Butnan et al. (2015) which were those pertaining to the charcoal traditionally produced from eucalyptus wood at low temperature at approximately 300°C. Meanwhile, the bases for 'bad' charcoal qualities were high ash charcoal (3.9%) with other properties 14.7% VM, and 81.5% fC) of eucalyptus wood charcoal produced under Flash carbonization™ (FC) technique at high temperature at about 800°C (Butnan et al., 2015). Another "bad" quality charcoal was a high VM (63.4%) one from corn cob under FC at low temperature with other properties including 1.6% ash, and 35.1% fC) (Deenik et al., 2011).

Data analyses

To identify the distribution of various charcoals with different qualities (VM, ash, and fC contents) obtained from the literature, we employed principal component analysis (PCA), and to clearly group these charcoals, we then superimposed k-mean cluster analysis onto the PCA to group similar charcoals with reference to their qualities together. Both analyses employed the XLSTAT statistic package version 7.5.2 (Addinsoft, Inc.).

Results

Among various charcoal production techniques, good quality charcoals (similar to a charcoal with low ash content (TK charcoal)) were generally produced under mud/clay kilns with restricted firing period, i.e., only during the initial phase, during production process (i.e., MB2, MB4, MB-B, and MB-F), and brick kiln with continuous firing using dry wood feedstock (i.e., BB-A) as well as Brazilian modified brick kiln (i.e., BM) (Figure 1). In contrast, bad quality charcoals (similar to FC charcoal) were obtained from rice husk mound (RM), mud kiln with continuous firing and extension of chimneys employing fresh (green) wood as feedstock (MB-G), and brick kilns with continuous firing using semi-dry wood (BB-D) and that with extension of chimneys using green wood (BB-G).

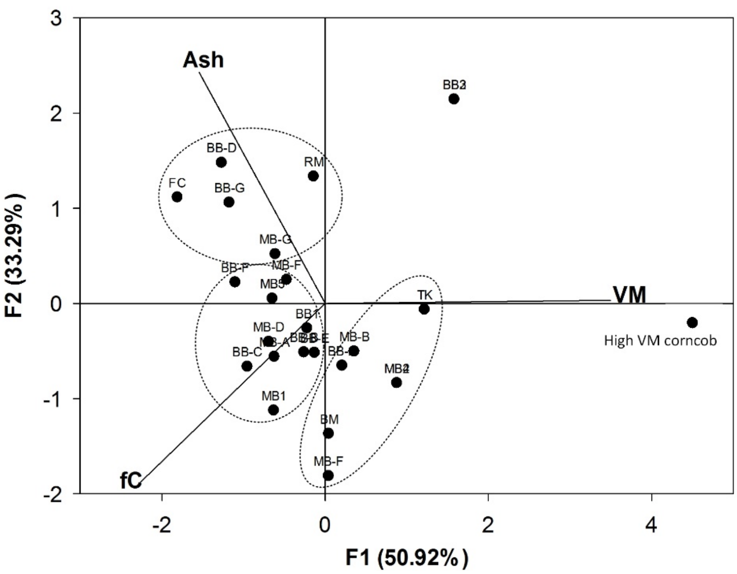

Figure 1 Principal component and k-mean cluster analyses of proximate analysis values (i.e., volatile matter, ash, fixed carbon contents) in different charcoal production techniques (n = 26) in Thailand. Abbreviations are detailed in the Appendix.

Regarding various feedstock of wood species, the good quality charcoal was produced from white cedar (**Figure 2**). In contrast, the bad quality charcoals were those originated from leucaena, casuarina, takeo bushwillow, and yellow batai as feedstock.

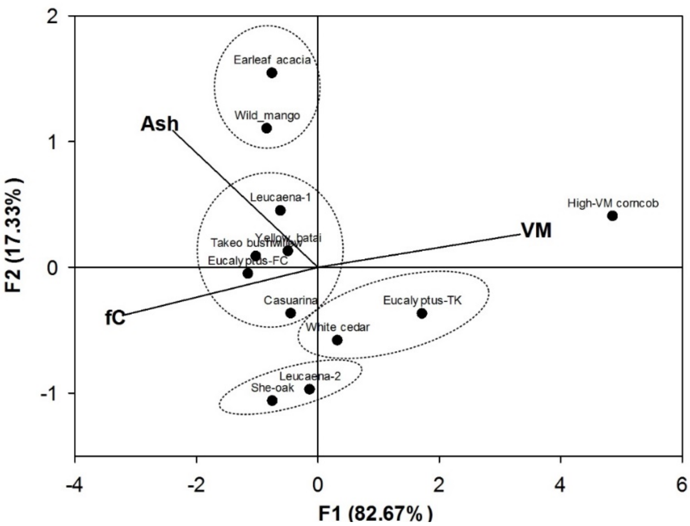

Figure 2 Principal component and k-mean cluster analyses of proximate analysis values (i.e., volatile matter, ash, fixed carbon contents) in different feedstock woods (*n* = 12) for charcoal production in Thailand. Abbreviations are detailed in Appendix.

Discussion

Classification of charcoal qualities

Production techniques and wood feedstock species are key factors influencing charcoal properties (Antal and Gronli, 2003). Of various charcoal properties, proximate values (i.e., fC, VM, and ash contents) play important roles in enhancement of soil fertility and plant growth (Butnan et al., 2015; Deenik et al., 2011; Deenik et al., 2010). In improving plant growth in acidic sandy textured soils in Northeast Thailand, our previous results showed that a TK charcoal brought about plant growth enhancement, it is therefore considered here to be 'good quality charcoal'. On the contrary, a charcoal possessed high ash (i.e., FC produced charcoal), which led to plant growth deterioration (Butnan et al., 2015), is perceived as 'bad quality charcoal'.

Among different production techniques in Thailand, mud and brick beehive kilns with firing only in the initial phase of burning timeframe by using dry woods produced good quality charcoals (low ash and VM contents). By contrast, those produced under rice husk mound as well as mud and brick beehive kilns with firing continuously through the burning process by using green woods yielded the bad quality (high ash content). As ash is the solid inorganic residue left after biomass is completely burned (Antal and Gronli, 2003) and O_2 is the stimulator of the combustion (Jayaraman and Gökalp, 2015), freely allowed O_2 flow of rice husk mound yielded the charcoal possessing high ash content. In addition to amount of O_2 flow, characteristics of wood feedstock, notably moisture content (mc) manifested in terms of fresh (green) or dry wood, also influenced charcoal's ash content (Darmstadt et al., 2000; Demirbas, 2004). Prolonged heating caused continuous water volatilization in high water content wood feedstock (>30% w/w). This, in turn, brought about heating degradation at a high level and loss of original structure of wood biomass (e.g., cellulose, hemicellulose, and lignin), and as a result, produced high ash content (Missio et al., 2013). This contention is consistent with the high ash content of semi-green (25 -30% mc) and green wood (> 30% mc) feedstock relative to that of dry wood counterpart (< 25% mc) as shown in the present paper (**Figure 1**).

Species of the wood feedstock is one of critical factors affecting charcoal qualities (**Figure 2**). Different wood species contain variable contents of biochemical structure (e.g., extractives, holocellulose, α-cellulose, and lignin) and alkali metals (Antal and Gronli, 2003; Antal et al., 1990). In general, the wood species having high lignin content produce charcoal with high fC content. Meanwhile, those possessing high content of alkali metals, particularly potassium (K), yield charcoals possessing high ash contents (Antal and Gronli, 2003; Antal et al., 1990). It is likely here that leucaena, casuarina, takeo bushwillow, and yellow batai had high alkali metals, particularly K. They therefore yielded charcoals possessing high ash content. They are considered bad quality charcoals in the context of their use as amendments for improvement of the coarse-textured low buffering capacity soils in Northeast Thailand. On the contrary, white cedar, a hardwood tree, likely contained low alkali metal content, in turn, yielded low ash charcoal relative to the earlier mentioned woods. As such white cedar has potential to produce a good quality charcoal for improvement and restoration of low fertility and acidic coarse-textured soils in Northeast Thailand in particular.

Implication of charcoal production for global environment

A number of reports have shown benefits of charcoal for improving soil fertility and plant growth as well as mitigating global warming problems (Verheijen et al., 2014). However, policy makers, conservation organizations, practitioners, and scientists in many countries are concerned that charcoal production may lead to deforestation and result in negative effect on global carbon balance, soil erosion, and soil fertility, as well as increases in emission to atmosphere of pollutant gases such as CO_2, CH_4, and CO from inefficient kilns (Chidumayo and Gumbo, 2013; Cline-Cole, 1998). However, Mwampamba et al. (2013) argued that it was a misconception of policy outlook on charcoal. No strong evidence has shown that deforestation is caused by charcoal production, because wood feedstock is generally obtained from residual woods from building construction, fallen branches, and dead trees (Junginger et al., 2001; Mwampamba et al., 2013; Wataru, 2003). However, this argument is still a subject of debate and more research is needed to address this issue (Ghilardi et al., 2013). Elucidation of carbon budget and atmospheric pollution effects are essential to understand environmental impacts of charcoal production. It is clear that charcoal production techniques need to be improved to reduce the release of pollutant gasses.

Conclusions

The results of the meta-analysis study showed that 'good' quality charcoal should have ash contents in the range of 1.6 -2.8% and VM content 20.4 -35.8%. As such good quality charcoal should be produced from dry woods of species similar in quality to eucalyptus and white cedar under relatively new type of kilns—mud and brick kilns—with limited pyrolysis period in the initial stage of production process to be used as a soil amendment in Northeast Thailand. In addition, other charcoals possessing contents of VM and ash in comparable levels to the good charcoals in the current study can be considered to be the good quality as soil conditioner. However, because there are many different soils in Northeast Thailand, a good charcoal quality for a specific soil may not necessarily be so in other soils. Further research is required to estimate soil properties and plant responses as affected by different charcoal qualities.

Acknowledgments

This study was funded by the Royal Golden Jubilee Ph.D. Program under the Thailand Research Fund (TRF) (PHD/0222/2549). Additional funding was from the Government of Thailand's Grants to Khon Kaen University (FY 2010-2016); TRF Basic Research Programs (2011 and 2015) (project no. DBG5480001, 2011 and BRG5880018, 2015). In addition, this paper was supported by the scholarship under the Post-doctoral Program from Research Affairs and Graduate School, Khon Kaen University (project no. 58107, FY 2015).

Appendix

Abbreviations

BB-A	= Average results of dry wood charcoal produced under brick beehive kiln using continuous firing
BB-B	= Average results of dry wood charcoal produced under brick beehive kiln firing at initial phase
BB-C	= Average results of green wood charcoal produced under brick beehive kiln using continuous firing and extension of chimneys
BB-D	= Average results of semi-dry wood charcoal produced under brick beehive kiln using continuous firing
BB-E	= Average results of green wood charcoal produced under brick beehive kiln using continuous firing
BB-F	= Average results of green wood charcoal produced under brick beehive kiln firing at initial phase
BB-G	= Average results of green wood charcoal produced under brick beehive kiln using continuous firing and extension of chimneys
BB1-3	= Average results of charcoal produced under brick beehive kiln
BM	= Brazilian modified brick kiln
Eucalyptus-FC	= Eucalyptus wood charcoal produced under Flash carbonization reactor using high temperature (600^{o}C)
Eucalyptus-TK	= Eucalyptus wood charcoal produced under clay kiln at low temperature (350^{o}C)
High-VM	= Corncob charcoal possessing high VM content produced under Flash carbonization reactor
MB-A	= Average results of dry wood charcoal produced under mud beehive kiln using continuous firing
MB-B	= Average results of dry wood charcoal produced under mud beehive kiln firing at initial phase
MB-D	= Average results of semi-dry wood charcoal produced under mud beehive kiln using continuous firing
MB-E	= Average results of green wood charcoal produced under mud beehive kiln using continuous firing
MB-F	= Average results of green wood charcoal produced under mud beehive kiln firing at initial phase
MB-G	= Average results of green wood charcoal produced under mud beehive kiln using continuous firing and extension of chimneys
MB1-5	= Average results of charcoal produced under mud beehive kiln
RM	= Average results of charcoal produced under rice husk mound

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