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Charcoal Production and Distribution as a Source of Energy and its Potential Gain for Soil Amendment in Northeast Thailand

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ABSTRACT

This paper investigates the historical development of charcoal production and distribution for energy purposes, as well as charcoal's possible use for soil amendment in Northeast Thailand. Charcoal evolution in Northeast Thailand has paralleled the pattern of change from subsistence to market economy. Small charcoal producers employ varied feedstock types from a wide range of low cost, locally available sources and use old-fashioned kilns i.e. permanent clay kilns or temporary rice husk mounds, whereas the larger producers use more uniform feedstock types and more modern, costly and permanent kilns i.e. the brick kiln. In contrast, several large-scale producers comprising multiple small producers continue to employ older production techniques. Charcoal distribution by small-scale producers is at subsistence level for home consumption and limited intra-community sale, while distribution by large-scale producers extend through wider market channels into urban communities. No direct evidence exists as to the deliberate use of charcoal for soil amendment in the region, despite the general knowledge of charcoal having (undetermined) soil improvement properties.Our research intends to examine charcoal's possible use for soil amendment through more thorough research into charcoal production and distribution in Northeast Thailand.

Keywords: Anthropogenic soil, charcoal kiln, indigenous production technologies, soil amendment, subsistence and market economies

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INTRODUCTION

Charcoal has been an energy source for humans for millennia, more recently, it has been considered as an alternative renewable energy source within developing countries (Mwampamba et al., 2013). It is both low in cost and easily attainable, compared to modern energy sources (e.g. liquid petroleum gas (LPG) and electricity). These factors are of particular importance to the poor in both urban (Ouedraogo, 2006; Shrestha et al., 2008) and rural societies (Nansaior et al., 2011). As a consequence of the recent increase in demand for charcoal, production has increased; it increased approximately 300% worldwide in 2013 (51.8 Mt) compared with in 1961 (16 Mt) (FAOStat, 2014). Southeast Asia produces a significant quantity of charcoal and Thailand was the largest producer in the region in 2013 (1.4 Mt), generating 2.7% of global charcoal production. Much of Thailand's charcoal is produced and consumed in Northeast Thailand's rural, sub-urban and urban communities (Junginger et al. 2001). On the basis of total energy consumed by a household through domestic activities, energy from charcoal constituted 21%, 16% and 6% in rural, sub-urban and urban communities, representing 11.5%, 9.6% and 3.3% of total energy consumption, respectively (Nansaior et al., 2011). Even though relatively small amounts of charcoal are used in the urban areas, urban dwellers still rely upon charcoal as an energy source for cooking some types of food such as native foods, as charcoal lends a distinctive taste to these dishes (Mwampamba et al., 2013; Nansaior et al., 2011).

Charcoal has been used as a soil conditioner since ancient times through *in situ* and *ex situ* practices. While the *in situ* methods involved biomass burning directly in the field (Carcaillet et al., 2002; Marlon et al., 2013), the *ex situ* methods required taking charcoal from external sources to the field (Montgomery, 2007; Pendleton, 1943). These practices were mainly to condition the soil to improve its fertility.

Much of the soil in Northeast Thailand is of low fertility due to natural factors related to soil formation as well as human factors related to intensive agricultural use (Vityakon, 2001). To enhance soil productivity, the use of organic materials for soil amendment has proved effective in improving fertility as indicated by the soil's physical, chemical and biological properties (Puttaso et al., 2013; Samahadthai et al., 2010; Vityakon, 2007). Recently, the use of charcoal for soil amendment has attracted research interest due to its promising agronomic (i.e. soil fertility and plant growth enhancement) and environmental (global warming mitigation) benefits (Macdonald et al., 2014; Verheijen et al., 2014).However, the impact of charcoal on both agriculture and the environment depends on the properties of charcoal (Butnan et al., 2015, 2016), which, in turn, are affected by feedstock type and burning conditions (Antal & Gronli, 2003).

Knowledge of source and type of wood and production technique as well as historical development of charcoal production and distribution is essential for effective policy making.Effective policies should have an acceptable balance between rural people's livelihood and environmental conservation, notably that of forest resources. In addition, this knowledge is essential for promoting charcoal used as a organic soil amendment to complement and reduce the existing use of chemical fertilisers. Published information on investigation into charcoal production in Northeast Thailand was collected from almost three decades ago. It has shown that limited feedstock was a major problem for charcoal production in rural Northeast Thailand (Polthanee et al., 1991) and tree plantation and more sustainable management of wood resources by villagers should be encouraged (Panya & Lovelace, 1988). More current information on these issues are scarce. We therefore investigated charcoal production and distribution as well as possible charcoal use for soil amendment in the Khon Kaen province of Northeast Thailand.

MATERIALS AND METHOD

Study Sites

The study was conducted in Nam Phong and Mancha Khiri districts of Thailand's Khon Kaen province where high volumes of charcoal (approximately 1,489 tons per year) (Tatayanon & Piriyayotha, 2016) are produced (Figure 1).

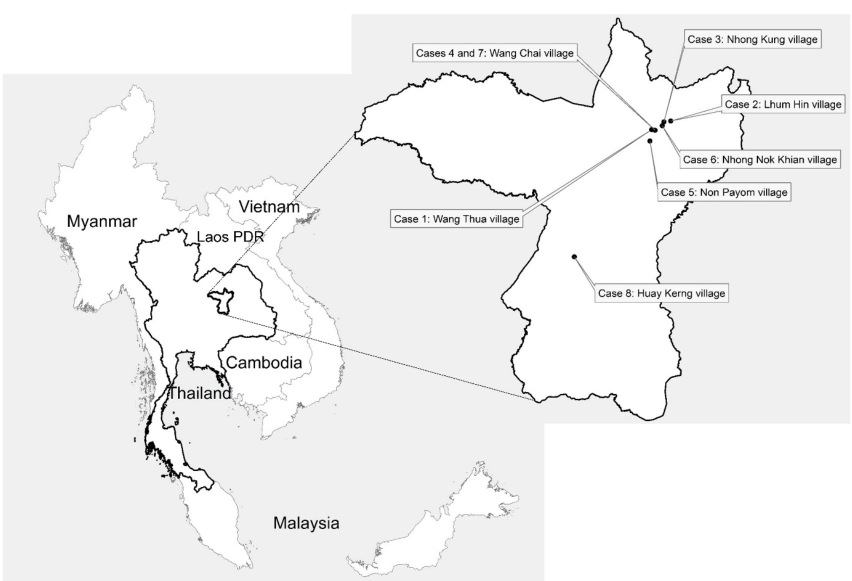


Figure 1. Location of study sites in Northeastern Thailand's Khon Kaen province

Data Collection of Charcoal Production and Distribution in Northeast Thailand

A preliminary survey based on observation and informal interviews with charcoal consumers and intermediaries in the province of Khon Kaen led to the selection of eight charcoal producers representing different production scales, technologies and organisational type. The production scale (small and large) was based on the number of charcoal kilns, while the technologies employed for production (old and new/modern) were based on kiln building materials.The different production organisational types included single producers as well as multiple groups (or aggregates of small producers) (Table 1). Small-scale producers were examined in Cases 1-5, whereas large-scale producers were examined in Cases 6-8.

Table 1
Scale and organisation of charcoal producers, number of kilns and location of cases within this study

Scale of Charcoal Producer	Organisation of Charcoal Producer	Kiln type		Number of kiln	Location of Case Study	
		Type[1/]	Type[2/]		Provincial area	Geographic coordinates
Small scale						
Case 1	Single	Clay kiln	Old	3	Wang Thua village, Nam Phong district	16˚68´39˝ N, 102˚82´79˝ E
Case 2	Single	Brick kiln	New	1	Lhum Hin village, Nam Phong district	16˚71´53˝ N, 102˚89´71˝ E
Case 3	Single	Clay kiln	Old	1	Nhong Kung village, Nam Phong district	16˚71´21˝ N, 102˚87´24˝ E
Case 4	Single	Brick kiln	New	2	Wang Chai village, Nam Phong district	16˚68´19˝ N, 102˚84´01˝ E
Case 5	Single	Brick kiln	New	2	Non Payom village, Nam Phong district	16˚64´25˝ N, 102˚82´16˝ E
	Single	Rice husk mound	Old	3		
Large scale						
Case 6	Multiple	Rice husk mound	Old	20	Nhong Nok Khian village, Nam Phong district	16˚69´81˝ N, 102˚86´61˝ E
Case 7	Single	Brick kiln	New	14	Wang Chai village, Nam Phong district	16˚68´19˝ N, 102˚84´01˝ E
Case 8	Multiple	Clay kiln	New	60	Huay Kerng village, Mancha Khiri district[3/]	16˚22´30˝ N, 102˚54´74˝ E

[1/]Kiln types classified based on their construction material
[2/]Kiln type classified based on technologies employed for production
[3/]A multiple (grouped) charcoal producer organised by officers of the state-owned Mancha Khiri Forest Plantation Station

Data collection from each of the eight pre-selected cases was in response to the two following major subtopics: (i) charcoal production methods i.e. kiln types and construction, feedstock types and sources, production techniques, and (ii) charcoal distribution. The two subtopics were evident in the semi-structured interviews following the rapid rural appraisal method (Conway, 1986). The interviewees from the small-scale production category consisted mostly of kiln owners and operators and represented five kiln owners in five different locations. From the large-scale production category, either an interview with a single operator or multiple interviews with multiple producers were conducted. In addition to kiln owners and operators, within the multiple producer category, a charcoal-production coordinator, an officer in the Mancha Khiri Forest Plantation Station, was interviewed.

RESULTS

Production of Charcoal

The charcoal production factors discovered from this research enabled a more in-depth understanding of charcoal production, as outlined below.

Feedstock types. Feedstock types in charcoal production are measured in production scales. The small-scale producers, who were categorised as Cases 1-5, used multiple types of wood feedstock such as mango, leucaena, rain tree and shorea, whereas their large-scale counterparts, Cases 6-8, employed less diverse types of wood feedstock such as eucalyptus or teak. However, Case 6, although a large-scale producer, actually consisted of numerous individual charcoal producers who shared common land for producing charcoal. These producers obtained their feedstock materials from a wide range of sources (Tables 2 and 3).

Feedstock sources. Similar to feedstock types, feedstock sources are also related to the production scale (Table 2). Small-scale producers, having low availability and small quantities of feedstock resources, obtain feedstock from their own farms i.e. crop fields and home gardens or cleared crop fields of other owners. Amounts and types of feedstock remained inconsistent, which could affect charcoal production. The feedstock sources of the large-scale producers were both large and consistent in supply. This type of producer acquired wood feedstock i.e. the upper parts of eucalyptus trees and fallen teak branches from either their own planted area (Case 7) or from state-owned plantations (Case 8), as shown in Table 2. An exception was Case 6, whose production was similar to that of small-scale producers.

Table 2
Kiln characteristics, feedstock types and their sources

Producer	Kiln						Feedstock					
	Type[1/]	Type[2/]	Size	Performance			Type	Number of Type	Source			
				Temperature (ºC)	Pyrolysis duration (days)	O_2 Access			Type	Number	Quantity	Consistently available?
Small scale												
Case 1	Clay kiln	Old	Small	~350[a/]	3	Limited	Mango, leucaena, rain tree and wild almond	6	Own farm: crop fields and home gardens	2	Small	No
Case 2	Brick kiln	New	Small	>500[b/]	3	Limited	Mango, shorea and more	>2	Trees in cleared crop fields	1	Small	No
Case 3	Clay kiln	Old	Small	~350[a/]	3	Limited	Mango and more	>1	Trees in cleared crop fields	1	Small	No
Case 4	Brick kiln	New	Small	>500[b/]	3	Limited	Mango, rain tree, white siris and more	>3	Trees in cleared crop fields	1	Small	No
Case 5	Brick kiln	New	Small	>500[b/]	3	Limited	Mango, eucalyptus and more	> 2	Trees in cleared crop fields	1	Small	No
	Rice husk mound	Old	Small	na	7	Freely accessible						
Large scale												
Case 6	Rice husk mound	Old	Small	na	7	Freely accessible	Mango, rain tree, shorea and more	> 3	Trees in cleared crop fields and wood from construction	2	Small	No
Case 7	Brick kiln	New	Large	>500[b/]	3	Limited	Eucalyptus and teak	2	Own tree plantation	1	Large	Yes
Case 8	Clay kiln	New	Small	~350[a/]	3	Limited	Eucalyptus	1	State-owned plantation	1	Large	Yes

na=data not available

[1/]Kiln types classified based on their construction materials

[2/]Kiln type classified based on technologies employed for production

[a/]Data obtained from Butnan et al. (2015)

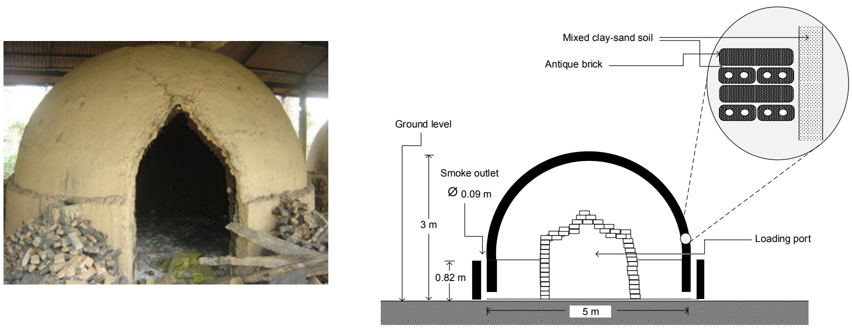
[b/]Data obtained from National Energy Administration (1984)

Table 3
Local (Thai), common and scientific names of feedstock used for charcoal production

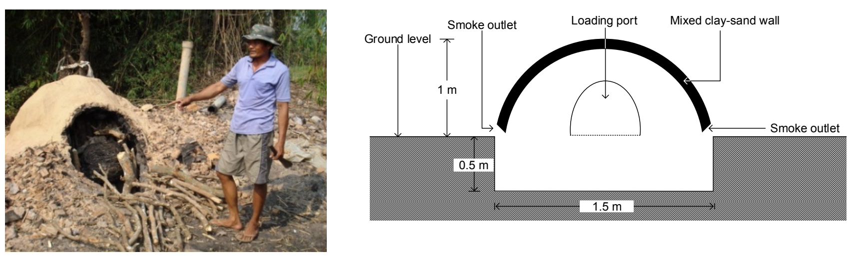
Local (Thai) name	Common name	Wood species
Chamchuree	Rain tree	*Samanea saman*
Eucalyptus	Eucalyptus	*Eucalyptus camaldulensis*
Kabok	Wild almond	*Irvingia malayana*
Krathin	Leucaena	*Leucaena leucocephala*
Ma-muang	Mango	*Mangifera indica*
Sak	Teak	*Tectona grandis*
Teng	Shorea	*Shorea obtusa*
Ton	White siris	*Albizia procera*

Kiln types and production techniques. Kilns can be categorised into three types: high-capital permanent kilns made of brick (Cases 2, 4, 5 and 7); low-capital permanent kilns made of clay (Cases 1, 3 and 8) and low-capital temporary kilns made of a rice husk mound (Cases 5 and 6), as shown in Table 2. The high-capital permanent kilns were often made of purchased bricks, whereas the low-capital ones were generally constructed from locally available clay, sand, rice straw or grass residue as illustrated in Figure 2b. The low-capital temporary kilns were constructed from materials that were locally available and without financial investment, with the exception of rice husk, which had to be purchased (Figure 2c).

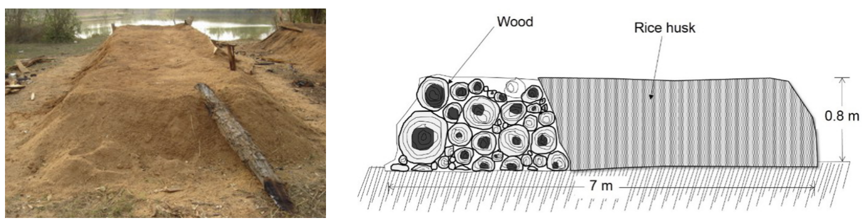
Charcoal production (Table 2) under the high-capital permanent (brick) kiln requires the pyrolysis temperature of approximately >500°C (National Energy Administration, 1984), while the low-capital permanent (clay) kiln can reach a temperature of approximately 350°C (Butnan et al., 2015). The duration of pyrolysis under limited oxygen for both kiln types is three days, after which the charcoal is cooled down (with or without the aid of water) and then air-dried for an additional four days. The temporary rice husk mound kilns require feedstock wood to be piled on them, then covered with fresh rice husk or a mixture of fresh and burnt rice husk. With this technique, the accessibility of oxygen is not restricted during pyrolysis. The free access to oxygen is indicated by visible flames. Pile volume and smoke colour are used as indicators of each burning stage. At the end of burning, the pile volume shrinks as the smoke turns from a white colour to blue and finally becomes colorless. Charcoal piles are cooled with the aid of water and air-dried for another two to three days.



(a)



(b)



(c)

Figure 2. Kiln types and their construction used for charcoal production in Northeast Thailand: (a) high capital and permanent kiln; (b) low capital and permanent kiln; and (c) low capital and temporary kiln

Charcoal distribution. Charcoal produced by single, small-scale producers is used mainly for home consumption and is available for sale to walk-in neighbours (Figure 3), as is common in the practice of subsistence economy. On the other hand, charcoal produced by single and multiple (group) large-scale producers is produced for commercial purposes and is fully integrated to the market economy. Large-scale producers distribute their charcoal through intermediaries. In urban areas in Khon Kaen, charcoal can be found in grocery stores and restaurants serving grilled food i.e. Korean BBQ and the Northeastern traditional dishes. Other charcoal products are sold along the highways such as Friendship Road. These charcoal products from the roadside and smaller grocery stores make their way to their final destination i.e. homes of residents for individual home consumption.

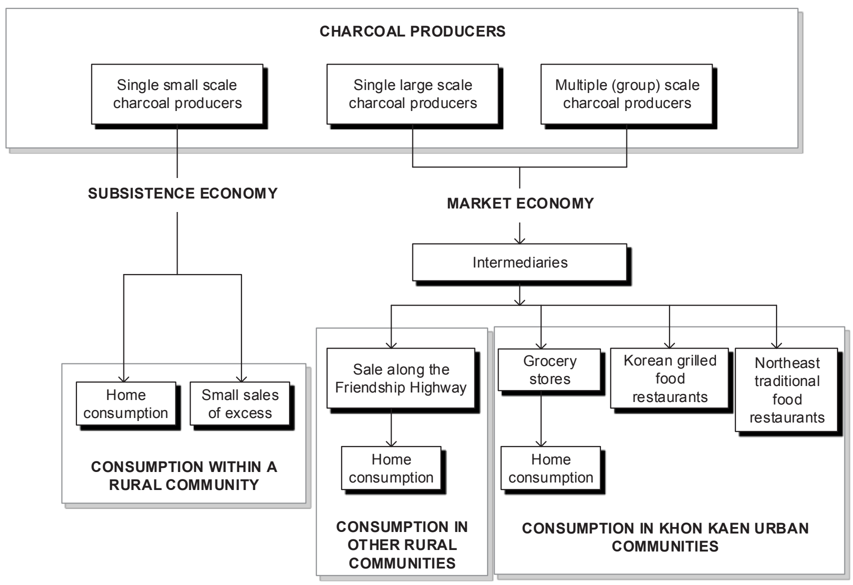


Figure 3. Channel of distribution of charcoal in Northeast Thailand

DISCUSSION

Factors Affecting Charcoal Production among Different Charcoal Producers

Charcoal production among different charcoal producers is mostly influenced by feedstock and production technologies. The more varied feedstock types used by single small-scale producers reflect their lower income, which drives them to procure raw materials from various non-costly, readily available wood feedstock sources such as crop fields and home gardens, fields undergoing land clearance for field crop production, community eucalyptus plantations or scaffold wood used in construction. Large-scale single producers have relatively higher incomes, which enable them to have their own eucalyptus and teak tree plantations as their major source of feedstock. Whereas the feedstock for large-scale single producers is more uniform than that of their small-scale counterparts, large-scale multiple (group) producers are uniform and varied in their source and type of feedstock.

Older technologies employing the clay kiln and rice husk mound operate under low temperatures (350°C), resulting in a low-quality charcoal product, with low fixed carbon and ash but high volatile matter, generating relatively low energy and yield. On the other hand, the high temperatures (500°C) of the newer brick kiln result in higher energy charcoal, due to the high fixed carbon content and low volatile matter generating higher charcoal yield. Despite the higher quality charcoal produced using the newer technologies, the investment costs are prohibitive on low-income producers. Single producers of both small- and large-scale categories demonstrate some degree of change in technology for charcoal production i.e. approximately 40% have adopted the brick kiln, often incorporating a mixture of both older and newer technologies. Despite their financial capability for adapting to the newer brick kiln technology, only a single large-scale single producer totally adopted the new brick kiln technology; so, a conclusive statement cannot be made regarding degree of adoption. Nevertheless, it can be postulated that larger-scale producers can afford changing to new higher financial investment technology due to their larger income compared with small-scale producers. This is substantiated by the fact that the only single large-scale producer was a retired schoolteacher with a regular monthly income from his pension. Kasemsrivivat (2003), who studied charcoal production and marketing of a reforestation co-operative in the Nam Phong district of Khon Kaen, also found large-scale producers to have higher income than their smaller-income counterparts. The large-scale multiple producers retained the older technologies i.e. using rice husk (Case 6) and a clay kiln (Case 8), similar to the small-scale single producers (farmers). However, there was some specific motivation or driving force that compelled them to come together as a group.

Case 8 had the largest number of kilns (60) and depeneded on a state-owned eucalyptus plantation, Mancha Khiri Forest Plantation Station, for feedstock materials such as eucalyptus wood, which is unfit for paper pulp. Historically, this plantation station belonging to the Forest Industry Organisation, organised the charcoal-making group by selecting households from the nearby village of Huay Kerng. The station also managed the distribution of the charcoal products for the producer group. There was evidence that the plantation station initiated changes in production technology through the construction of a brick kiln for demonstration; however, most lower-income participants did not embrace the new technology or its costs and continued the traditional use of clay kilns. A more complete change was seen in large-scale single producers having higher incomes. In addition to the financial factor, local knowledge of charcoal making further determined the changes in production technology, as both small-scale and multiple large-scale producers had employed their own traditional methods. Similar to Northeast Thailand, the Laos PDR also employed primarily older methods of charcoal production e.g. rice straw mound, mud kiln and earthen caves influenced by their education, available technology and wood feedstock resources (Mekuria et al., 2012).

Distribution of Charcoal Products

The distribution channels for charcoal products in the Northeast greatly reflect the change from subsistence to market economy. Small-scale charcoal makers produce only small amounts of charcoal used mainly in households within their own rural community, whereas the larger producers i.e. single and multiple large-scale producers distributed larger amounts along marketing channels through intermediaries to urban communities. Excess charcoal produced by smaller producers for their subsistence consumption is often sold to village neighbours for similar subsistence use i.e. cooking fuel. In contrast, the higher volumes of charcoal products by both single and multiple (group) large-scale producers are distributed within a market economy via marketing channels to a variety of consumers further afield i.e. households and restaurants in various urban communities such as the city of Khon Kaen. The use of charcoal as fuel energy for cooking is still favoured in Northeast Thailand, as well as in many other countries worldwide, due to its distinctive aroma, which is locked in the food, giving it a unique taste (Nansaior et al., 2011). Intermediaries are commonly engaged for further distribution as highway vendors i.e. the Friendship Road, resulting in more widespread distribution.

The History of Charcoal Use for Non-Energy Purposes and Its Possible Future Use for Soil Amendment in the Northeast

The burning of biomass as a soil conditioner for crop growth has been practised since ancient times. It has been done *in situ* through the burning of growing biomass in the field itself i.e. slash-and-burn shifting cultivation or *ex situ* by gathering and bringing biomass to the field as was the ancient practice of the Amazons, who developed the famous rich black soil known as *terra preta*. Historically, both methods are used throughout Thailand’s Northeast. The *in situ* method of the late Pleistocene and Holocene periods has been reported by Kealhofer (1996). Throughout the mid-Holocene period, farmers pioneered the cultivation and settlement of forests and grasslands through slash-and-burn practices (Carcaillet et al., 2002; Marlon et al., 2013). Since then, burning has been carried out due to the establishment of settlements, landscape fragmentation, road construction, governmental policies and other forms of land management (Murdiyarso & Label, 2006). Throughout Southeast Asia, countries continue to manage their field crops through the burning of weeds prior to cultivation, the burning of sugarcane prior to harvest and the burning of remaining rice stubble in paddy fields before ploughing for the next rice crop (Kealhofer, 1996). This practice of burning biomass could enhance short-term soil fertility and crop productivity by an increase in soil pH (liming) and a decrease in aluminium toxicity (de Rouw, 1994). However, burning of rice fields could result in loss of soil organic matter (11%), beneficial microorganisms and some plant nutrients such as nitrogen (12-80%), phosphorus (17-25%), potassium (up to 17%) and sulfur (up to 60%) (Mandal et al., 2014; Roder et al., 1995).

The *ex situ* practice of biomass burning involves charcoal production transposed to the field. Rural villagers in Northeast Thailand make charcoal primarily for energy; however ,observations have been made in soil fertility improvement (soil darkening) through the amendment of residual charcoal and ash (Montgomery, 2007, pp. 143–144; Pendleton, 1943). Additionally, burnt or carbonised rice husk is used as potting mix in nurseries (Annapurna et al., 2005). Research has found that charcoal has been used for soil amendment, especially in coarse-textured soils, as it improves the soil's chemical and physical properties (Oka et al., 1993). The motivation of this area of research was based upon the abundance of rice husk during post-harvest seasons. Other Southeast Asian countries such as Malaysia have applied charcoal and burnt domestic waste to add to soil in their household backyards. This mixture is termed *tanah hitam* (black soil) (Ng, 2009).

The beneficial effects of charcoal for use in soil amendment have been found to produce different effects within each specific type (Mukherjee & Lal, 2014). In the coarse-textured soils of the Northeast i.e. the Korat soil series positive plant growth responses were obtained with not more than 4% (by weight) application rate of low ash, high volatile matter (VM) charcoal produced from eucalyptus wood at low (350°C) temperatures. Conversely, negative plant responses were found under applications of high ash low VM charcoal produced from the same feedstock, but at high (800°C) temperatures (Butnan et al., 2015). To expand upon these results, we employed published data on charcoal production from various wood feedstock under different techniques, as provided by Thailand's National Energy Administration (1984) (data not shown). We determined that low alkali metals, especially potassium, in woods resulted in low ash charcoal and that the wood feedstock should be mature (as opposed to green wood), with low moisture content (Antal & Gronli, 2003). Given these findings, we propose that the ultimate wood feedstock suitable for soil amendment should have the following parameters (under proximate analysis): fixed C in the range of 62-78%, VM, 20-36% and ash, 1.6-2.8%. Eucalyptus wood charcoal produced under low temperatures must be of significant quality i.e. fixed C, 62%, VM, 36% and ash, 2.4%, while high temperature feedstock is of low quality i.e. fixed C, 82%, VM, 15%, and ash, 4%. We also determined the white cedar (*Melia azedarach*), a fast growing tree in the Northeast, to be of the best quality feedstock for charcoal production for soil treatment with a fixed C of 74%, VM, 24% and ash, 2.8%).

Charcoal continues to be the preferred cooking fuel in Thailand's Northeast region, despite increasing availability of alternative, more modern types of cooking fuel i.e. LPG, owing mainly to its capacity to impart distinctive qualities (notably taste and aroma) (Nansaior et al., 2011). As for the use of charcoal for soil amendment, a similar trend may be found, based on a strong foundation of local knowledge and local practices of biomass burning for soil improvement, in conjunction with continued research. Charcoal properties, influenced by feedstock type and production conditions, notably pyrolysis temperature, pressure and duration, are important factors in production, as they directly affect soil properties and crop growth. The quantity of available raw materials used as feedstock further influences production through financial investment related to charcoal purchase and application costs. An application rate for a coarse-textured upland soil of 1% w/w (Butnan et al., 2015) or an equivalent of 22 tons per hectare is equal to a cost of US USD3,699 (at USD7.70 per 42 kg charcoal bag). This level of investment is considered extreme for a small farmer of the Northeast, whose yearly income per household is approximately USD2,000. The demand for charcoal for soil amendment may be high for horticultural crops with intensive cultural practices. However, demand for charcoal for field crops may gather strength due to the severe degradation of agricultural soil in the region, where the demand for once virtually valueless organic materials from industrial wastes i.e. filter cake from sugar mills exists. Additionally, charcoal is recalcitrant in nature, resulting in its persistence in soil over time and lends long-term influence through a single application. It is therefore plausible that a single investment for an initial application can give long-lasting effects to soil and crops for an extended period of time. Further research is called for on these various emerging issues.

SUMMARY AND CONCLUSION

The results of this study have revealed the parallel nature of the history of charcoal production and the economic changes from subsistence to market economy in Northeast Thailand. While small charcoal makers continued to employ varied feedstock types from a wide range of locally available, non-costly sources in conjunction with old-fashioned clay or rice husk mound kilns, large producers use more uniform feedstock types from their own fast-growing tree plantations as well as a new type of kiln made of bricks. However, another category of producers, the multiple producer, is made up of a collective group of smaller charcoal makers working together as a large-scale producer, employing production techniques considered as intermediate between their single small and large-scale counterparts. They have adopted the practice of uniform wood feedstock from large plantations, yet employ old-fashioned kilns depending on the individual producer's income level and technological knowledge. Complete adoption of new charcoal production technology found only among single large-producers is due to their higher income and knowledge, relative to their smaller producer counterparts. Larger, state-owned plantations play a key role in organising the producer groups and supply them with regular and uniform feedstock; however, this has not yet translated into the adoption of new types of kiln.

Distribution of the charcoal products of small-scale producers is similar to that of the subsistence economy pattern, where households consume their own production and any excess is sold to the community. Excess products are not distributed widely. On the other hand, production of the large-scale producers is distributed as done in a market economy, much more widely through market channels to varieties of consumers in both rural and urban communities.

It appears that charcoal production and distribution by small producers have faced a major problem of limited and inconsistent feedstock sources. Measures can be taken to group them together to collectively produce feedstock, such as through establishing a cooperative tree plantation to serve as their reliable source of feedstock. Culturally and historically, in Southeast Asia charcoal has been used to improve soil through both *in situ* and *ex situ* practices. However, successful charcoal application for soil amendment must consider various impacting factors notably, charcoal and soil quality interactions, supply quantities for competing uses, such as energy and soil improvement agents, and cost of the charcoal applications. All these necessitate further research.

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REFERENCES

Annapurna, D., Rathore, T. S., & Joshi, G. (2005). Refinement of potting medium ingredients for production of high quality seedlings of sandalwood (*Santalum album* L.). *Australian Forestry, 68*(1), 44–49.

Antal, M. J., & Gronli, M. (2003). The art, science, and technology of charcoal production. *Industrial and Engineering Chemistry Research, 42*(8), 1619–1640.

Butnan, S., Deenik, J. L., Toomsan, B., Antal, M. J., & Vityakon, P. (2015). Biochar characteristics and application rates affecting corn growth and properties of soils contrasting in texture and mineralogy. *Geoderma, 237*, 105–116.

Butnan, S., Deenik, J. L., Toomsan, B., Antal, M. J., & Vityakon, P. (2016). Biochar properties influencing greenhouse gas emissions in tropical soils differing in texture and mineralogy. *Journal of Environmental Quality, 45*(5), 1509–1519.

Carcaillet, C., Almquist, H., Asnong, H., Bradshaw, R. H. W., Carrión, J. S., Gaillard, M. J. W., Kathy, J. (2002). Holocene biomass burning and global dynamics of the carbon cycle. *Chemosphere, 49*(8), 845–863.

Conway, G. R. (1986). *Agroecosystem analysis for research and development.* Bangkok, Thailand: Winrock International.

Deenik, J. L., McClellan, T., Uehara, G., Antal, M. J., & Campbell, S.(2010). Charcoal volatile matter content influences plant growth and soil nitrogen transformations. *Soil Science Society of America Journal, 74*(4), 1259–1270.

de Rouw, A. (1994). Effect of fire on soil, rice, weeds and forest regrowth in a rain forest zone (Côte d'Ivoire). *Catena, 22*(2), 133–152.

FAOStat. (2014). *ForestStat – Wood charcoal statistics.* Retrieved November 25, 2014, from http://faostat.fao.org.

Junginger, M, Faaij, A., van den Broek, R., Koopmans, A., & Hulscher, W. (2001). Fuel supply strategies for large-scale bio-energy projects in developing countries: Electricity generation from agricultural and forest residues in northeastern Thailand. *Biomass and Bioenergy, 21*(4), 259–275.

Kasemsrivivat, S. (2003). *Comparison between inside and outside groups of reforestation co-operative for production and marketing management of eucalyptus charcoal in the area of Nampong district, Khon Kaen province in the year 2002* (Master's thesis), Khon Kaen University, Khon Kaen, Thailand.

Kealhofer, L. (1996). The human environment during the terminal pleistocene and holocene in northeastern Thailand: Phytolith evidence from Lake Kumphawapi. *Asian Perspectives, 35*(2), 229–254.

Macdonald, L. M., Farrell, M., Zwieten, L. V., & Krull, E. S. (2014). Plant growth responses to biochar addition: An Australian soils perspective. *Biology and Fertility of Soils, 50*(7), 1035–1045.

Mandal, K. G., Misra, A. K., Hati, K. M., Bandyopadhyay, K. K., Ghosh, P. K., & Mohant, M. (2004). Rice residue – Management options and effects on soil properties and crop productivity. *Food, Agriculture and Environment, 2*(1), 224–231.

Marlon, J. R., Bartlein, P. J., Daniau, A. L., Harrison, S. P., Maezumi, S. Y., Power, M. J., … & Vanniére, B. (2013). Global biomass burning: A synthesis and review of holocene paleofire records and their controls. *Quaternary Science Reviews, 65*, 5–25.

Mekuria, W., Sengtaheuanghoung, O., Hoanh, C. T., & Noble, A. (2012). Economic contribution and the potential use of wood charcoal for soil restortion: A case study of village based charcoal production in central Laos. *International Journal of Sustainable Development and World Ecology, 19*(5), 415–425.

Montgomery, D. R. (2007). Dirt: The erosion of civilization. Los Angles, CA: University of California Press.

Mukherjee, A., & Lal, R. (2014). The biochar dilemma. *Soil Research, 52*(3), 217–230.

Murdiyarso, D., & Label, L. (2006). Local to global perspectives on foest and land fires in Southeat Asia. *Mitigation and Adaptation Strategies for Global Change, 12*(1), 3–11.

Mwampamba, T. H., Ghilardi, A., Sander, K., & Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development, 17*(2), 75–85.

Nansaior, A., Patanothai, A., Rambo, A. T., & Simaraks, S. (2011). Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand. *Biomass Bioenergy, 35*(10), 4180–4188.

NEA. (1984). *Charcoal production improvement for rural development in Thailand.* Bangkok, Thailand: National Energy Administration.

Ng, F. S. P. (2009). Horticultural carbon, terra preta, and high-performance horticulture in the humid tropics. *Journal of Science and Technology in the Tropics, 5*, 79–81.

Oka, H., Rungrattanakasin, W., Arromratana, U., & Idthipong, S. (1993). Improvement of sandy soil in the Northeast Thailand by using carbonized rice husk. *JICA Techical Report, 13*, 42–49.

Ouedraogo, B. (2006). Household energy preferences for cooking in urban Ouagadougou, Burkina Faso. *Energy Policy, 34*(18), 3787–3795.

Panya, O., & Lovelace, G. (1988). *Charcoal making in rural northeast Thailand: Rapid rural appraisal of a wood-based small-scale enterprise.* KKU-Ford Rural Systems Research Project, Khon Kaen University.

Pendleton, R. L. (1943). Land use in Northeastern Thailand. *Geographical Review, 33*(1), 15–41.

Polthanee, A., Suphanchaimat, N., & Na-Lampang, P. (1991). Urban-rural wood energy interdependency in a district of Northeast Thailand. In N. Jamieson (Ed.), *Wood fuel flows: Rapid rural appraisal in four Asian countries* (pp. 167–201). Bangkok: FAO Regional Wood Energy Development Programme in Asia.

Puttaso, A., Vityakon, P., Rasche, F., Saenjan, P., Treloges, V., & Cadisch, G. (2013). Does organic residue quality influence carbon retention in a tropical sandy soil? *Soil Science Society of America Journal, 77*(3), 1001–1011.

Roder, W., Phengchanh, S., & Keoboulapha, B. (1995). Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos. *Plant and Soil, 176*(1), 27–36.

Samahadthai, P., Vityakon, P., & Saenjan, P. (2010). Effects of different quality plant residues on soil carbon accumulation and aggregate formation in a tropical sandy soil in Northeast Thailand as revealed by a 10-year field experiment. *Land Degradation and Development, 21*(5), 463–473.

Shrestha, R. M., Kumar, S., Martin, S., & Dhakal, A. (2008). Modern energy use by the urban poor in Thailand: A study of slum households in two cities. *Energy for Sustainable Development, 12*(4), 5–13.

Tatayanon, S., & Piriyayotha, T. (2016). *Woodfuel flow in Khon Kaen province.* Bangkok: Research Report of Wood Energy Development, Royal Forest Department.

Verheijen, F. G. A., Graber, E. R., Ameloot, N., Bastos, A. C., Sohi, S., & Knicker, H. (2014). Biochars in soils: New insights and emerging research needs. *European Journal of Soil Science, 65*(1), 22–27.

Vityakon, P. (2001). The role of trees in countering land degradation in cultivated fields in Northeast Thailand. *Southeast Asian Studies, 39*(3), 398–416.

Vityakon, P. (2007). Degradation and restoration of sandy soils under different agricultural land uses in Northeast Thailand: A review. *Land Degradation and Development, 18*(5), 567–577.