Burn to air or burial in soil: The fate of China's straw residues

Genxing Pan[*], David Crowley[¶], Johannes Lehmann[§]
[*]Nanjing Agricultural University, Nanjing 210095-China; [¶]University of California Riverside, CA 92521, USA; [§]Cornell University, Ithaca, NY 14853, USA

One of the most important, but under utilized biomass resources in the world today is the large amount of straw that is generated from the production of crop plants such as wheat, rape seed, and cotton. Currently, most of this biomass is burned resulting in air pollution and loss of a potential carbon feedstock for improving soil fertility. This problem is especially evident during the months from May to June, when winter wheat and rape seed crops under double cropping with summer rice are harvested in southern China. Burning straw residues in the field generates black carbon particulates, giving rise to deteriorated air quality in adjacent cities. In 2011, the air pollution caused by this practice was especially serious due to the severe "100-year" drought in southern China. Following severe levels of air pollution in May in Chengdu City, the capital of Sichuan, the largest agricultural province of Southwest China[1], the cities in metropolitan urban area of Yangtze Valley Delta region all suffered extreme air pollution to the extent that it was reported in the local media on the World Day of Environment[2,3,4], led to cancellation of many airplane flights and caused breathing problems for the urban populations[5,6]**.**

Due to these problems, straw burning in the field has been banned by the administration of China's government. Nonetheless, combustion of straw has not yet stopped by the farmers. Even in Hefei, the capital of Anhui in the lower reach of Yangtze Valley, a first ticket for burning wheat straw in violation of ban on burning was issued shortly after the wheat harvest in early June[7]. Such extensive burning in obvious violation of the government regulations reveals a threat to China's agricultural and environmental quality that is of equal concern to problems caused by non-point pollution from nutrient runoff and soil acidification[8]. This even raises high concerns by the top leadership of the Chinese government party, which is now calling for "far more than a ban"[9] .

Fig. 1 A, Rape seed crop straw burning in suburb of Chengdu, Sichuan, May, 2011; B, A farmer burned wheat straw on World Environment Day, June 5, 2011).

Burning of crop straw is also a concern with respect to increasing greenhouse gas emissions in China. Globally, greenhouse gas emissions from the agricultural sector contribute 14%, whereas emissions from agricultural sources account for 17% of China's total emission as reported in the first national Communication on Climate Change of the Peoples Republic of China in 2004. The total cultivated croplands under rice, wheat, maize and cotton amounts to 155 Mha and a total biomass production amounts to 1300 Mt. In turn, the resulting straw wastes from these crops have been estimated to be 0.7 Pg dry mass in 2006. In Henan Province, the central plain of north China, approximately 25% of the straw material is burned to prepare the fields for the next crop[10]. In other areas the problem is worse, such as in Jiangsu Province, where straw burning has increased from 21% in mid-1990's to 48% in mid-2000s[11].An overall annual CO_2 emission from straw burning in the field could amount to as much as 0.2 Pg, corresponding to 15% of the total CO_2 emissions generated from energy production in China. Therefore, proper disposal of straw is an urgent concern not only for control of air pollution and improvement of environment quality of human being, but also for reducing GHG emissions from China's fast developing economy.

In western countries, biochar production via pyrolysis of agro-biowastes and return to field is being pursued as a New Green Agriculture technology[12,13], which is promoted globally by the International Biochar Initiative. This environmental-friendly and sustainable agricultural technology also deserves priority for China, who has committed to reduce the CO_2 intensity by 40-45% by 2020 as compared to 2005. As an option for meeting this requirement, a state project of Green Energy County Demonstration was launched in 2010 jointly by the State Bureau of Energy, State Ministry of Finance, Ministry of Agriculture of China[14]. This project is being performed in 108 counties, with which the gasification, formulated combustion material and marsh gas from crop straw is being encouraged through state incentives[15]. However, recycling of crop straw is still a challenge with respect to developing efficient mechanisms for return to soil.

Soil organic carbon(SOC) sequestration makes an important contribution for mitigating climate change[16] and the sequestration capacity of China's croplands may be as high as 2-3 Pg C[17]. By comparison, the mean SOC storage of China croplands is estimated to be 1/3 lower than that of US and European agricultural soils[18]. The huge capacity for SOC sequestration in China could be fed largely by crop straw input. However, this will require development of new infrastructure as land fragmentation and non-business management of crop production by subsistence farmers diminishes the incentive to recycle straw in the field[10]. This problem poses a great challenge for meeting the goal of reducing GHGs reduction ambition while developing the real capacity of agricultural production of China[19].

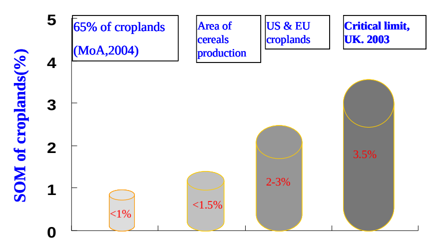

Fig. 2 A comparison of cropland SOC between China and EU and USA

Nevertheless, great efforts by Chinese scientists and engineers have never stopped in establishing a practical solution for recycling the crop straw in fields. These efforts have been targeted to a properly organized collection of crop straw in fields and biomass pyrolysis to produce biochar for return to fields. After several year trials, a consecutive pyrolysis kiln (Fig. 3A and B) to convert straw biomass into syngas and biochar as well as pyrolinetical solution was formulated in 2010 in Henan Province[20], which has been the largest producer of cereal grain in China over the last decade. With this technology, 800 cubic meters of syngas and 350 kg of biochar can be obtained with pyrolysis of one ton of wheat straw without external energy consumption. The collection in field and proper storage of large amounts of straw for such a pyrolysis plant, further required a mechanism for local farmers to purchase these products and a storage facility that rents strapping machines for the straw bales. By this mechanism, the collection of straw from fields is allowed with economical compensation to land owners and the storage keeper sells the compacted straw to the company, which makes a business for local farmers. Of course, such a mechanism will not work efficiently with the very fragmented croplands, especially in poor regions such as in the loess hills and plateau region. Thus a small scaled pyrolysis system using a simplified vertical kiln also was developed in Sanli New Energy Company, Henan (Fig. 3C), which allows an in-situ biochar and syngas production from straws collected in the vicinity and that further supplies gas for cooking and household use, while the biochar produced can be returned directly to local fields. With the small pyrolysis system, farmers can exchange straw harvested from their own fields for gas energy linked to their house. For the very fragmented and SOC poor croplands such as in Shanxi Province, a group of farmer engineers developed a mobile pyrolysis system which can be driven by a tractor to the cropland and convert biomass into only biochar for directly return to the fields(Fig. 3D). This pyrolysis machine can treat without exotic energy wheat or maize straw 400-500kg and produce 120-150kg of biochar per hour, which is almost the crop straw produced in one *mu*(1/15 ha). Meanwhile, some agronomists from Northeast China have recently innovated a small scale fixed pyrolysis kiln for farmer use in their field when they harvesting the maize (Fig 3D). In this way, in situ carbonization of maize straw with pyrolysis is achieved in convenience of farmers and without much time consuming. These mobile or fixed small scale systems may offer the farmers an opportunity to burn the straw as biochar for burial in their soil instead of burning to air, which is expected to encourage under the government incentives.

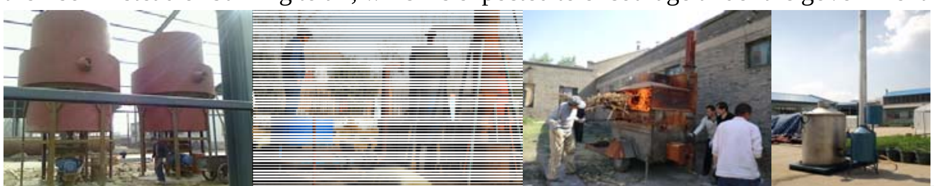

Fig. 3 A, vertical kilns of large scale pyrolysis system□B, a small scale pyrolysis systemfor use in village; C, a mobile pyrolysis system and D, a fixed in situ pyrolysis kiln.

The potential role of biochar for enhancing soil productivity and improving soil environmental quality has been received much attention from Chinese agronomists and soil scientists. A group of soil scientist and agrochemists from the Institute of Resource, Ecosystem and Environment of Agriculture, Nanjing Agricultural University (IREEA-NAU) have been conducting field experiments on biochar's effect on soil reclamation and mitigation of greenhouse gases emission from croplands for a number of years. In the first report of Chinese biochar field study, their cross-site field study across China's mainland have demonstrated consistently large effects of biochar amendments on reducing N_2O both from dry croplands and rice paddies[21]. Thus they recommend the return application of biochar converted from crop straw as a major option to reduce N_2O emission in fields for China's crop production[22]. Recently, another field study from this group has shown a surprising effect on reducing toxic heavy metals uptake and accumulation in cereals grains in polluted fields[23]. They believe that biochar amendment will bring a bright prospect for ameliorating Cd-polluted rice field for safer rice production in southern China rice areas, where Cd pollution is becoming increasingly extensive and excessive Cd in rice becomes a public concerns[24]. Moreover, in a new field study completed in June 2011, Pan's group has succeeded in developing an effective measure to ameliorate salt affected soil and to ensure normal wheat growth in the area of ancient valley of Yellow River, in Henan Province. They employed a coupled amendment of biochar with the acid pyrogenous solution from biomass pyrolysis and obtained a normal wheat yield of 6.7t/ha in a soil with salt content 0.5% and pH over 10 compared to only 0.6t/ha in un-ameliorated salt land and 4.3t/ha with normal reclamation measures of organic fertilization operated by farmers [Fig. 4D]. A patent is being issued of such a technology for fast reclaiming the extensive salt affected soils and a field demonstration of such amendment for large scale amelioration of saline soils is being operated in the costal lands of Jiangsu [Fig. 5], where a large area of new lands are emerging due to marine deposition of sediments. According to their findings of beneficial effects of biochar amendments in croplands, they have formulated some biochar products for commercial use in the agricultural sector, such as biochar based combined fertilizers, foliar growth promoters, and green growth media for nursery plants and flowers. A number of patents of such products are being issued.

As a brilliant prospect for the industrialization of pyrolysis for converting agricultural waste into biochar and associated products, biomass companies, agronomists and pyrolysis engineers

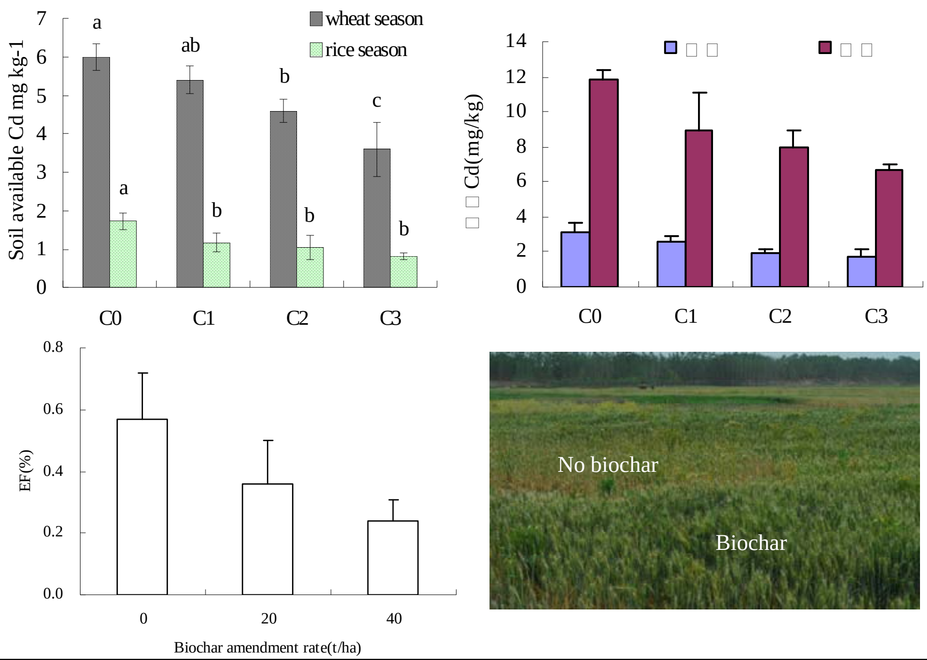

Fig. 4. A, Biochar effects on reducing Cd mobility in soil□B,Biochar effects on reducing Cd accumulation inrice and wheat grains; C, Biochar effects on depressing EF ratio of chemical N fertilizers and D, wheat growth in biochar and pyrogenous solution ameliorated salt affected soil.

Fig. 5. A large scale demonstration of biochar amendment-aid reclamation of saline soils in costal lands of Jiangsu.

have agreed to establish a partnership for further extending the production and application of biochar as a new green agriculture technology. Following a concise policy briefing to the central government last year[25], a well documented recommendation of developing biochar enterprises in China is being transferred to the Chinese authority. For information exchange and expertise sharing, an international workshop will be hold in Nanjing, hosted by the Institute of Resource, Ecosystem and Environment of Agriculture (IREEA, NAU) in September, 2011 when the Chinese partnership of biochar will be launched. In the near future, biochar production of crop straw can be expected to extend over China, with which straw burning in field would be greatly avoided for a better and green agriculture.

Fig. 6 Biochar associated agro-products innovated in IREEA, NAU. A, biochar based fertilizer and the liquid foliar growth promoter; B, biochar heavy metal stabilizer; C, Biochar biofert)

Refs cited:

1. http://news.workercn.cn/rollnews/c2/2011/0519/319607154.shtml.
2. http://zjnews.zjol.com.cn/05zjnews/system/2011/06/01/017564902.shtml
3. http://news.qq.com/a/20110604/000377.htm.
4. http://ah.anhuinews.com/system/2011/06/04/004111373.shtml.
5. http://news.ifeng.com/mainland/detail_2011_06/04/6826041_0.shtml.
6. http://ah.anhuinews.com/system/2011/06/04/004111373.shtml.
7. http://news.hefei.cc/2011/0603/020038249.shtml.
8. Ju, X. T., Xing, G.X., Chen, X.P. et al., 2009. Reducing environmental risk by improving N management in intensive Chinese agricultural systems. PNAS 2009, 106 (9), 3041-3046.
9. http://cpc.people.com.cn/GB/64093/64099/12931299.html.
10. Ma, J. Cause of straw burning in field by China's farmers: A analysis of cost-benefit and policy barriers. Journal of Agrotechnical Economics, 2009, no2, 77:84. (in Chinese)
11. Liu, L. H. Greenhouse gases emissions from agricultural residues burning" A case study of Jiangsu province, China. MS thesis, Graduate School, Nanjing Agricultural University, 2011.
12. Lehmann J. A handful of carbon. Nature, 2007, 447: 143-144.
13. Taylor, B.2010. The Biochar Revolution: Transforming Agriculture & Environment. Global Publishing Group, USA.
14. http://www.newenergy.org.cn/Html/0114/4281139956_2.html.
15. http://www.sdpc.gov.cn/zcfb/zcfbtz/2010tz/t20101119_381246.htm.
16. Smith P, Martino D, Cai Z C *et al*. Greenhouse gas mitigation in agriculture [J]. Philosophical Transactions of the Royal Society B., 2008, 363: 789-813.
17. Lal, R., 2004. Offsetting China's CO_2 emissions by soil carbon sequestration. Climatic Change 65, 263–275.
18. Pan, G. 2009. Stock, Dynamics of Soil Organic Carbon of China and the Role in Climate Change Mitigation, Adv. Clim. Change Res., 2009, 5 (Suppl.): 11-18.
19. Zheng, J. F., Pan, G., Cheng, K., et al., 2011. Perspectives on study on soil carbon stock and carbon sequestration potential of China. Chinese Science Bulletin, in press.
20. http://sanlixinnengyuan.com/news.asp?NewsId=390&class=2.
21. Zhang, A.F. Cui, L.Q, Pan, G. et al., 2010. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture Ecosystems and Environment 139, 469-475.
22. Liu, X.Y., Qu, J.J., Pan G., et al., 2010. Emission intensity of N_2O from chemical N fertilizer in

China’s rice production can be greatly reduced under biochar amendment: a cross site field experiment. *Climate Change,* under review.

23. Cui, L.Q., Zhang, A.F., Pan, G. et al., Biochar greatly reduces rice Cd uptake in a contaminated paddy soil: a two-year field experiment. *Bio-resources,* 6(3), 2605-2618.
24. New food scare: some cadmium with your rice? http://blogs.wsj.com/chinarealtime/2011/02/16/new-food-scare-some-cadmium-with-your-rice
25. Pan, G., Lin, Z.H., Li, L.Q. et al. 2011. Perspective on biomass carbon Industrialization of organic waste from agriculture and rural areas in China. *J. Agric. Sci. Technol*., 13(1): 75-82.