# Low Tech Production and Application of Biochar in Mongolia

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**Abstract**

The beneficial potential of biochar as a soil amendment to enhance plant growth and sequester carbon for significant climate change mitigation is widely known, although there is some disagreement as to whether this is the general case or more usually restricted to depleted tropical soils. The current paper reports on two experiments to gauge the potential benefits of biochar in the northern dry, high altitude steppe climate with extremes of temperature and the poor sandy soil and the development of designs for biochar ovens suitable for economical biochar production by smallholders for their own use.

**Key Words:**

Biochar, biochar ovens, steppe climate, Mongolia, smallholders, low tech biochar production, soil amendment, climate change mitigation

**Introduction:**

The beneficial potential of biochar as a soil amendment to enhance plant growth and sequester carbon for significant climate change mitigation is widely known [1, 2] and has led to a recommendation that it be used in dryland areas subject to potential desertification for soil remediation and carbon sequestration. [12] While exact results depend on numerous variables including feedstock type, char production parameters, application procedures, soil type and crop; a typical response is to be able to achieve similar or better crop production with decreased fertilization, peaking, in general, with a treatment of about 1kg dry wt biochar per square meter of soil. When put in the soil as a soil treatment the recalcitrant char can be sequestered for hundreds to thousands of years, representing a long lasting reduction in atmospheric CO2.

It has been estimated that enough plant material is produced each year that could be utilized in an ecologically friendly and sustainable manner as biochar feedstock to offset 12% of the worlds CO2 pollution. [3] Over half of this potential, however, represents thinly distributed feedstock not concentrated in such a manner as to be economically utilizable by large high tech machines producing multi tons of biochar per day. [4] And the potential from concentrated feedstock sources is likely to be further reduced by economic competition from bioenergy uses. [5] However, if a practical, inexpensive, easy to fabricate and use, non-polluting means for the smallholders of the world to produce and utilize biochar for their own benefit could be developed, then much of the thinly distributed feedstock could be utilized for enhanced food security and significant, timely climate change mitigation.

The climate change crisis has a time line with a "tipping point" not far off. [6] Although high tech biochar production is not likely to reach its potential within the time remaining before the tipping point is reached [3, 5, 6] it seems obvious that smallholders would adopt the use of biochar if it was to their economic benefit. Thus the climate change mitigation potential of thinly distributed feedstock could be brought on line before the tipping point is reached if a means of getting the information on biochar's benefit to individual smallholders and the means of achieving it could be brought to them in time, bringing economic benefit to the smallholders as well as climate change mitigation benefit to the world.

UB International (UBI) [7] has developed a program to achieve this through introducing production and use of biochar to pilot communities of smallholder farmers, herders and forestry workers. Through working with pilot communities of different culture/environment types, the potential of biochar would be adapted to their particular needs and desires. Once adapted to a particular culture/environment type a program of communities-mentoring-communities, initiated by interested members of the original pilot community and furthered by members of ensuing mentored communities in conjunction with trained community development workers could achieve the necessary exponential growth to quickly spread the production and use of biochar in that culture/environment type. [7, 8] Once shown to work in a range of culture/environment types, the concept would be available for large NGOs, GOs & IGOs to utilize as they begin to focus on the urgency of climate change and the drawback of the lengthy development time inherent in their usual implementation of entirely new programs.

The work reported on here constitutes some of the work initiated by UBI in Mongolia in conjunction with the Mongolian Biochar Initiative (MoBI), [9] an informal consortium of individuals, NGOs and universities, to test the UBI concept in Mongolian environment/culture types.

**Winter wheat one month grow-out**

**Methods:**

As a preliminary test of the potential of biochar to facilitate plant growth in Mongolia, advantage was taken of sawdust biochar produced in the development of low tech biochar ovens (retorts) to conduct a one month October grow out trial in a warm house.

A 3 x 6 m plot was laid out in the native soil (sandy valley soil in the ger district of Ulaanbaatar) of a warm house (a partially heated greenhouse) and divided into 6 strips of 3 x 1 m. They were cultivated to a depth of 20 cm with standard hand tools after dressing every other strip with the sawdust derived biochar at 1 $kg/m^2$. All strips were seeded in the same manner with winter wheat. All plots were intentionally keep on the same low water regime. After approximately 30 days the grow-out was terminated due to increasingly cold weather making further growth problematic. Plants were carefully dug up and loose soil gently removed, inspected and photographed.

**Results:**

Plants representative of the response are shown in fig. 1. There was a difference in above ground and below ground growth discernable to the naked eye, showing increased growth in the biochar treatment (plants on the left). However, the difference in below ground growth was particularly evident. Not only are the roots from the treatment plots longer, they are markedly more robust looking with a black granular outer coating. This coating was undoubtedly composed of the grains of biochar. It could

Fig. 1

Fig. 2

be removed, but held with sufficient tenacity to indicate that root hairs and/or fungal hyphae were penetrating the biochar pores.

**Field trial with a standard potato crop.**

**Methods:**

A sandy 0.3 ha field on a valley floor in the ger district of Ulaanbaatar was selected for a controlled summer grow-out test of the biochar under ordinary cultivation conditions in the area. A soil test pit was dug and photographed and the field divided into 2 treatment areas, one treated with biochar at the rate of 10 t/ha (1 $kg/m^2$) mixed in with hand tools to a depth of approximately 20 cm. The other area was without added biochar. Both areas were planted in the same standard manner with Impala variety potatoes. The biochar was obtained from a commercial source using large, brick, open bay, bottom lit, natural up draft kilns and feedstock from a historic sawdust pile. The biochar produced had been stored under cover for several years. It was originally produced for the purpose of making charcoal briquettes.

Soil samples were taken in each area at 3 sites with 6 samples at each site before treatment and after harvest, each set sent to a laboratory (the Petrologic Laboratory of the Geological Institute, Australia) for soil analysis: compost content, pH, nitrate, phosphorus and potassium. In addition, the number of bacteria in a plated 1 g soil sample from 3 sites, one each from the pre treatment field and both of the treatment areas at the end of grow-out. At the end of the grow-out period each treatment was sampled at 3 locations with 6 sample areas of 1 $m^2$ harvested and weighed.

**Results:**

The soil test pit revealed that the grow-out field consisted of undifferentiated sandy soil throughout the potato root growth horizon and beyond. [Fig. 2] The soil

| 1 | Indexes | Index before cultivation | After crop harvest: Biochar treatment | After crop arvest: Control | Difference: Biochar treated land | Difference: Control land |
|---|---|---|---|---|---|---|
| 1 | Compost% | 3.92 | 3.64 | 3.69 | -0.28 | -0.23 |
| 2 | pH | 8.53 | 8.04 | 8.02 | -0.49 | -0.51 |
| 4 | $NO_3$-N mg/kg | 15.12 | 12.3 | 12.76 | -2.82 | -2.36 |
| 5 | Dynamic $P_2O_5$ mg/100g | 2.80 | 2.46 | 2.8 | -0.34 | 0 |
| 6 | Dynamic $K_2O$ mg/100g | 14.68 | 4.6 | 5.5 | -10.08 | -9.18 |

Table 1. Soil Analysis

| Sample number | Number of bacteria in 1g soil of area before cultivation cell/g | Number of bacteria in 1g soil of area after crop harvest cell/g | | Variation in number of bacteria in 1g soil of area after harvest cell/g | |
|---|---|---|---|---|---|
| | | Fertilized | Unfertilized | Fertilized | Unfertilized |
| 1st sample | 3,900,000 | 155,000,000 | 4,300,000 | 151,100,000 | 400,000 |
| 2nd sample | 2,775,000 | 740,000,000 | 3,120,000 | 737,225,000 | 345,000 |

| | | | | | |
|---|---|---|---|---|---|
| 3rd sample | 3,320,000 | 94,000,000 | 3,720,000 | 90,680,000 | 400,000 |
| Sum of 3 samples | 9,995,000 | 989,000,000 | 11,140,000 | 979,005,000 | 1,145,000 |
| Average | **3,331,667** | **329,666,667** | **3,713,333** | **326,335,000** | **381,667** |

Table 2. Soil Bacteria counts

| **Sample number** | Crop /kg/ of 1 sq m area of control | | | | Crop /kg/ of 1 sq m area biochar treatment | | | |
|---|---|---|---|---|---|---|---|---|
| | **Area 1** | **Area 2** | **Area 3** | **Average** | **Area 1** | **Area 2** | **Area 3** | **Average** |
| **1** | 2.270 | 1.575 | 3.045 | 2.297 | 3.850 | 3.850 | 3.675 | 3.792 |
| **2** | 1.435 | 4.200 | 2.590 | 2.742 | 2.975 | 2.555 | 2.520 | 2.683 |
| **3** | 2.870 | 3.395 | 3.010 | 3.092 | 3.360 | 3.150 | 3.010 | 3.173 |
| **4** | 3.500 | 3.325 | 2.425 | 3.083 | 3.990 | 3.325 | 3.430 | 3.582 |
| **5** | 2.415 | 1.890 | 2.800 | 2.368 | 3.885 | 3.570 | 3.185 | 3.547 |
| **6** | 3.150 | 3.320 | 2.870 | 3.113 | 3.430 | 3.990 | 4.130 | 3.850 |
| **Sample sum** | 15.640 | 17.705 | 16.740 | 16.695 | 21.490 | 20.440 | 19.950 | 20.627 |
| Sample average | 2.607 | 2.951 | 2.790 | 2.783 | 3.582 | 3.407 | 3.325 | 3.438 |
| **Estimated Crop per hectare, control** | | | | | | | **27.9** | |
| **Estimated Crop per hectare, biochar treatment** | | | | | | | **34.4** | |
| **Estimated Crop difference per hectare** | | | | | | | **6.5** | |

**Table 3. Crop weights at end of grow out period.**

analysis is shown in Table 1, the tests for soil bacteria numbers are given in Table 2, and the harvest results in Table 3.

**Development of the 200 l hallow core retort biochar oven.**

**Methods:**

This oven was developed to take advantage of the plentiful supply of inexpensive 200 l barrels commonly known as 'oil drums' and the related type fully open at the top with a clamp on lid. After a few trial runs with smaller drums using available sawdust as a feedstock, it was decided to use a clamp top 200 l barrel with a hollow core of approximately 15 cm diameter running vertically up the center of the barrel with 6 sets of 4 6 mm gas ports (1 set each at near the bottom, 1/5, 2/5, 3/5, 4/5 the way up and near the top). This core pipe was open to the outside at both the top and bottom of the barrel. Although the oven was loaded through the top of the barrel, for firing the barrel was inverted so that the bottom of the oven was what would ordinarily be considered the top of the barrel. (This was done so that any leakage of pyrolysis gases from around the barrel lid would be ignited by the fire underneath the oven.) A ring of 8 equally spaced holes (base gas ports) 6 mm in diameter was located in the bottom end the oven near the base opening of the core. Another ring of 8 6 mm gas ports was located on the wall of the oven near the lower rim. After filling the barrel with feedstock and inverting it, the oven was placed on a low metal grating and both surrounded by light weight sheet metal cylindrical cowling with openings at ground level to enable stoking a fire (the primary heating fire) under the grating, and to allow in primary air and inspection of the nature of the flames associated with the gases exiting the bottom oven gas ports. The pyrolysis gases were ignited by the fire and also contributed to the heating of the oven. The top of the cowling was covered by several sheets of metal that could be arranged in various configurations to roughly regulate the amount of updraft across the fire, up the central core and up the sides of the oven. The test ovens were run with a variety of feedstocks beginning with sawdust, which was the first available feedstock, and a series of modifications made in an effort to improve performance.

**Results:**

From the beginning we could not achieve pyrolysis of a full load of sawdust feedstock in the 200 l retort ovens, due, it became evident, to the insolating nature of the feedstock itself preventing heat penetration. In an attempt to overcome this, 2 opposed gas ports at each level in the core pipe (except at the top and bottom; see fig 6) were enlarged and smaller lateral pipes inserted which terminated, open ended, close to the outer wall of the feedstock chamber. An opening on the upper side at the middle of the section of these lateral pipes, situated within the core pipe, was designed to create a 'venturi effect' negative pressure by the hot gases rushing up the core pipe. This, aided by the positive pressure of the generated pyrolysis gas from the feedstock in the chamber, was hoped to draw hot gases from near the core pipe through the feedstock mass to near the inner side of the feedstock chamber wall and then out to the core pipe through the lateral pipes. It was hoped that this would initiate enough circulation through the feedstock mass to cause pyrolysis throughout the feedstock load. As can be seen from fig 6 it wasn't, at least not within a reasonable burn energy/time.

To confirm that the problem was likely the suppression of gas circulation, a test was run with the feedstock chamber divided into 3 equal sections. One section was loaded with dry sawdust from the same feedstock source as previously used, one with granular paddock manure, and the third with field dried horse manure. [Fig 3] The oven used was the same as that described immediately above and operated in the


Fig. 3

typical fashion. The results for the sawdust section were as previously seen, partial pyrolysis near the heated surfaces grading precipitously to slightly charred and raw sawdust. For the granular paddock manure the results were slightly better but otherwise similar. (The paddock manure probably had higher moisture content than the dry sawdust but the particle size was larger.) The field dried horse manure yielded biochar throughout its section. The large ovoid pieces of horse manure would seem to have allowed for good circulation within that feedstock mass.

Given this result and the success in developing a different design that could successfully handle sawdust type feedstock we concentrated further development of the hollow core design using feedstock types that allowed for sufficient heat circulation within the feedstock chamber. Our objectives were to lower the fuel consumption in heating the oven while achieving high biochar porosity, simplicity of design and mobility.

Greater mobility was investigated through the elimination of the cowling. Lowering fuel consumption was investigated by increasing internal heat circulation through making the lateral arm pipes of the hollow core system abut directly on the main hollow core pipe with an air tight fitting instead of passing through the core pipe loosely fitted as before. The other gas ports were eliminated. This change would force all of the pressure generated within the feedstock chamber to force the hot gases out to the outer wall of the feedstock chamber before passing through the arms and into the main core pipe where these gases would burn in the core pipe and add to the heat generated by the primary fire beneath the oven. The outer circular wall of the feedstock chamber was covered in light weight insulation to help retain heat in the feedstock chamber since it was no longer being heated by hot gases being directed up the sides of the feedstock chamber by a cowling. Also, a two level fire box was developed with an upper level for heating the bottom of the feedstock chamber which is penetrated by the lower end of the core pipe to be heated by its own fire in the lower level that can be regulated to allow sufficient $O_2$ in the core pipe for its changing needs. [Fig. 4]

Fig. 4

Fig. 5

A second design was perused in parallel which emphasized simplicity of design. This design also eliminated the cowling and had an insolated outer feedstock chamber wall, but eliminated the lateral arms from the core pipe (but retained the gas ports) and reduce the heating fire box to a simple "3 stone fire" design.

The two designs were run in a side by side comparison test, each with one half of the same preparation of feedstock. The feedstock consisted of a mixed lot of dry stove wood slabs reduced to 2-3 x 3-5 x 6-8 cm sticks, dry chunked cow manure and dry goat manure in its natural pellet form.

As can be seen in Fig 4, the oven with the lateral core pipe design and split level fire box had a clean burning pyrolysis gas flare. The other design also had such a clean burning flare. Both ovens were run until the flame characteristic of burning tars and oils ceased to be seen exiting from the gas ports even when the primary heating was stoked strongly. This was achieved later with the oven with the 3 stone fire box and simple core pipe. Both ovens produce good looking biochar throughout the feedstock chamber. [Fig. 5] The oven with the split level fire box and lateral arm core pipe produce 24% biochar on a dry weight bases while the other produced 27%, indicating that the former likely produced biochar with less tars and oils and with greater porosity than the later. However, different crews ran each of the ovens so the resulting differences cannot necessarily be attributed to design.

The next phase of testing will be to turn to multiple 20 – 35 l TLUD gasifiers as a primary heat source. These small ovens could be replaced as needed. (If at the end of their orange flame phase, these small TLUD ovens are replaced they would be producing their own biochar.) If the TLUD heating ovens are removed pyrolysis flare of the large retort this would produce a low temperature biochar in the retort. If heating were continued, a higher temperature could be achieved if the TULD heating ovens were maintained until the tars and oils had also been expelled, even by continuing them in their runs beyond the biochar production phase to allow burning through the carbon burning phase if necessary to produce a higher retort temperature (and ash for fertilizer from the TLUDs).

Also to be continued is side by side testing of the elaborate and simplified designs.

**Rectangular metal box oven.**

**Methods:**

Sawdust and other feedstocks that, by their nature become closely packed and tend to prevent the easy circulation of gases, do not pyrolyze to biochar throughout the feedstock mass in a simple 200 l barrel retort oven with a reasonable expenditure of time and heating energy. However, the pyrolysis process can go to completion within approximately 10 cm of the heated surface. [Fig. 6]

Fig. 6

Fig. 7

Therefore, in an effort to develop a large volume, simple retort oven for these types of often abundant feedstocks we tested a prototype design consisting of 5 simple metal box retorts 60 cm on the sides by 10 cm deep. [Fig. 7] Each box had a pattern of gas ports on each broad side and a simple slipover cover for loading which was situated on the bottom during firing so that escaping gases would be ignited by the fire beneath. The lids were secured by a metal strap or wire around the center of the retort with a loop on the side opposite the lid so that each retort could be handled at the end of firing. The 5 retorts were set facing broadside to each other about 10 cm apart on a low grating under which the primary heating fire was lit. The narrow space between the retorts acted as a fire box for the gases escaping from the adjacent retorts. These gases were ignited by the flames of the primary heating fire below.

The boxes and fire grating were surrounded by a cowling made of light weight sheet metal for containing and directing the burning gases. It was raised from the ground sufficiently to allow enough air for the fires and had accommodation for restocking the primary heating fire. The top of the cowling consisted of a cover of movable metal sheets that could be configured to balance the updraft for sufficient aeration of the fires and the desirability of retaining their heat for effect.

Various feedstocks were run in the retorts to gauge the performance of the oven.

**Results:**

The initial run with sawdust feedstock produced biochar throughout each chamber showing that that this simple natural draft design was capable of producing biochar from feedstock that usually requires a higher level of technology. Other, more usual feedstocks for low tech retorts (wood shavings, small sticks, etc.) also yielded good results. [Fig. 8] Since the critical element in the design is the narrow depth of the

Fig. 8

retort boxes, the volume of feedstock handled at one time could be greatly increased simply by increasing the length and height of each retort, and/or the number of retorts in the unit. The boxes were made of only moderately heavy gauge sheet metal and they warped. While still usable for this developmental work, it did not appear that they would have a long half life. For a serviceable unit heavier gauge metal would be needed and/or reinforcing by bending in ridges and/or affixing reinforcement during fabrication.

**UB 200 l natural draft TLUD gasifier J-RO oven.**

**Methods:**

In the literature, most work on retort biochar ovens report on the efficiency of converting the feedstock into biochar, but ignore the fuel used to heat the retort process which itself is often a suitable biochar feedstock. In Mongolia, where biomass is often the primary source of fuel for smallholders and often expensive, this is not a trivial consideration. For this reason we began considering heating our retort oven with several top lit, up draft (TLUD) gasifiers, larger than typical cook stoves. [10] While very large TLUDs had a reputation of being rather unmanageable and requiring sophisticated technology, the smaller cook stove technology was simple and fairly well understood. At about this time a biochar enthusiast, John Rogers, had gone ahead and tried to make a natural draft TLUD oven, much larger than the usual large TLUD cook stove, from 200 l drums utilizing only simple technology. A YouTube video of the results was made. [11] While incorporating some fortuitous, little understood design features and a tendency towards unacceptable smoke pollution, it was simple, did produce biochar in quantity and without the need to attend to an external fire. It was decided to make a test bed 200 l natural draft TLUD oven, originally designated as the UB JR 200 l Oven. [Fig. 9, 10] The design was intentionally over elaborate to allow easy experimentation on the parameters of primary air flow, secondary air flow, and chimney draw. These are important parameters affecting TLUD performance [10] and seemed to have been met fortuitously in the John Rogers oven.


Fig. 9


Fig 10


Fig. 11


Fig. 12

The test bed oven consisted of:

1. A feedstock chamber: a 200 l open top barrel with a pattern of 54 holes, 13 mm each, in the bottom. [Fig. 11] These are the primary air ports and the pattern is designed to enhance even distribution of air across the feedstock column.
2. A primary air chamber: the bottom 3$^{rd}$ of another 200 l barrel of the same diameter on which the feedstock chamber sits. Eight square 7 x 9 cm openings, equally spaced around circumference of the chamber were cut in a ring around the side of the chamber near the bottom. A slip ring with corresponding ports was situated over these ports so that the functional air volume entering the

primary air chamber, and thus the amount of up draft volume, could be adjusted.

3. An afterburner: Black carbon of smoke in the atmosphere is thought to be hundreds of times more potent as a green house gas on a per weight bases than $CO_2$. Since a TLUD operates on limited air to minimize carbon burning by the flame front in the feedstock chamber, a TLUD oven would produce prodigious amounts of smoke if the unburned gas produced in the process were allowed access to the atmosphere. The afterburner serves to burn these gases to $CO_2$ and $H_2O$. It was made of the top 3rd of the second barrel with a 30 cm diameter 1 m tall chimney in the center of the clamp top. It was fitted with a similar slip ring and port system as the primary air chamber as a means of regulating the air flow into the afterburner chamber. The chimney was fitted with an adjustable damper as a means of controlling the afterburner updraft. [Fig. 12]

[If a matching set of barrels cannot be found that allow for a snug fit between the feedstock chamber and the primary air chamber and afterburner then a fringe of short tabs can be cut in the cut edges of the second barrel sections and bent alternately in and out to allow for a snug seating of the feedstock and afterburner chambers with minimal air leakage.]

**Results:**

The initial test of the oven was made with a load of chunked dry cow manure as the feedstock. The ports on the primary air chamber were left fully open and those on the afterburner were 4/5 closed. The chimney damper was ½ closed. The run was terminated after 55 min when no more orange flame was observed in the after burner.


Fig. 13


Fig. 14

As can be seen by the burn line in the paint on the side of the oven [Fig. 13] the flame front was still quite even after almost 1/3 of the way through the feedstock, but became increasingly irregular as the burn neared completion [Fig. 14]. No hot spots were observed below the burn front, however. As also can be seen in figures 13 & 14, the oven was smokeless during operation.

Another run was made with a similar feedstock load several weeks later with similar results except that the burn required 100 min to complete the orange flame phase.

A burn also using dry cow manure in this type of oven was run with two temperature probes connected to a data logger. Both probe tips were located in line 23 cm inside feedstock chamber wall, one 18 cm from the bottom and the other 18 cm from the top. The upper probe was effectively just below the bottom of the afterburner at the beginning or the run which gradually transition to become the upper 1/3 of the afterburner chamber as the feedstock / biochar mass slumped during the burn do to the shrinkage of the feedstock / biochar volume with process time. The resulting time/temperature curves are shown in figure 15.

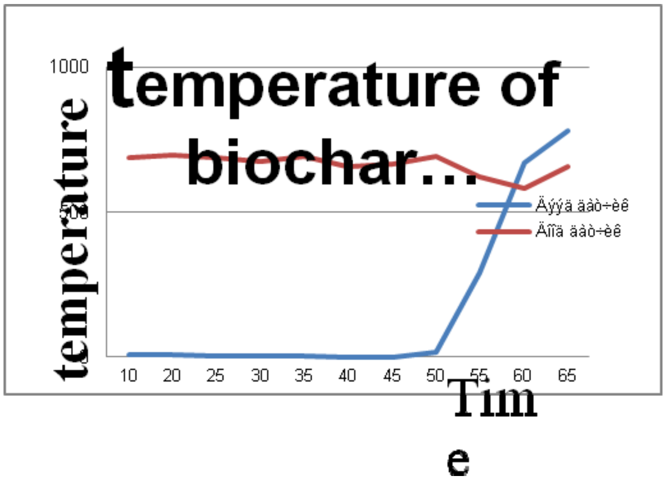

Fig. 15  Fig. 16

A few weeks after the completion initial phase of this work we learned of another group, headed by Dr. Hugh McLaughlin in Massachusetts, USA who were also working on developing 200 l TLUD biochar ovens after being inspired by the same John Rodgers video. They had been working primarily on forced draft versions and hybrid ovens with a 150 l retort over and heated by a 200 l TLUD. It was agreed that it would be worthwhile for the two groups to get together to exchange ideas and practical training. The meeting was attended by one of the authors (Frogner), Hugh McLaughlin, John Rodgers, Doug Clayton, Paul Anderson and interested workshop students.

As a result of these discussions and observations made with the UB JR 200 l TLUD test bed oven, a new, simplified 200 l TLUD natural draft biochar oven was designed, the UB Jolly Rodger Oven, or the UB J-RO (the 'UB' designation has been adopted as the general designation for J-RO ovens). [Fig. 16] This oven features the much simpler H McL afterburner, made by the top of the oven separated from the feedstock chamber rim by a pair of 2 – 7 cm metal bars functioning as the top of the afterburner. The bottom of the afterburner is created by the top of the feedstock/biochar mass. The oven is clean burning throughout the run, but is prone to an uneven flame front with hot spots developing below as can be seen [Fig. 17] during the initial test run with a load of woodchip feedstock after less than 1/5 of the burn. Never the

 Fig 17  Fig. 18

less, when the burn was quenched at the end of the orange flame phase there was an ample load of biochar. [Fig 18] The pattern of primary air holes was standardized as 37 holes arranged in the circled square design. [Fig. 19] (See [7] July 2012 update, for instructions on how to quickly lay out this pattern with just a length of chord, a straight edge and a marking pen.)


Fig. 19


Fig. 20

The total volume of primary air is determined by the diameter of the primary air holes. Thus it can be varied by choosing different diameters for them. If the feedstock chamber is made from a open-ended barrel with the open end down, then different diameter holes can be made in a set of lids one of which is clamped on the bottom of the oven as appropriate for the run at hand. [Fig. 20]

**Discussion:**

The initial grow out trials, while simple and lacking in sophistication and depth of analysis, were sufficient to show that biochar produced in low tech ovens and kilns could have a positive effect on crop growth. The finer points of biochar potential are notoriously dependent on crop, feedstock type, production conditions, inoculation, soil type and conditions and time in the ground. [1,2] It is imperative then, that further, more elaborate grow out experiments be done including with well analyzed biochar produce under known conditions within the range of parameters expected to be generally employed and encountered.

Currently there is some difference of opinion as to whether biochar produced at low temperature (300 – 400 C) or at higher temperature (600 – 800) degrees produces more desirable effects. At this point this cannot be theoretically determined from the known data because of the number of other variables involved. It will need to be settled through grow out trials under actual use conditions. In any case, whichever proves true (or more likely, under what conditions each, or various mixtures of each will prove best) the above work with the various biochar ovens puts us in a good position to pursue our goals by having economical, easy to fabricate and use ovens for the smallholder that can produce a serviceable biochar within the limits of the feedstock itself.

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