Bikultivator: Cultivating our way through Zambia

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March 17, 2015

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Executive Summary

The desire to address social needs, interest in community innovation, and passion for resource recovery to mitigate the laborious task of early season weeding in North and Northwestern Zambia are the foundation of the Bike Cultivator: a row-crop push-tool designed by client Jordan Blekking in 2012. Our D-Lab project sought to provide improvements for this push cultivator, formerly known as the Northwestern Bike Plow. Through a series of proposed modifications our objective was to make this push cultivator more farmer-friendly, versatile, crop sensitive and soil conserving. The methods used to achieve this goal were drawn from a variety of UC Davis practitioners, sustainable agriculture literature resources, and contemporary push plow designs and techniques. This project presented economic, social, environmental, and technical opportunities to optimize the bike cultivator.

Final Problem Definition

Team Bikultivator's client was Jordan Blekking, a former Peace Corps Volunteer currently located in Zambia, Africa. He served his two-year time with the Peace Corps a few years ago, and in 2012, nearing the end of his service, he constructed an agricultural tool that could be utilized by the locals in Zambia to save time cultivating and weeding. This tool was constructed from an old bicycle found in town, with a hoe blade fabricated from scrap metal attached to the bottom (see figure 1 below). It was reported that this tool addresses the need for Zambians to cut down the time and effort put forth to cultivate and weed the land. It was following this that he reached out to D-lab in order to see where else this novel tool could go and

Figure 1: Team Bikultivator; Gabriel Patterson (Left), Elyssa Lewis (Middle), Tony Ricciardi (Right)

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Figure 2: Original Bike Plow *Source: Dropbox photograph shared by Daniel Quinn*

At the beginning of this project, it was stated that "Students working with this project will be asked to conduct a feasibility study to review assumptions (i.e. 50% labor time savings), determine the prospects for local fabrications of Jordan's design, and access the scalability of the technology" (D-Lab, 2014). This was the thought process the first week of the project. However, after discussing with Jordan numerous times over the phone and on Skype, it was decided that he would much more prefer to utilize time doing three simple tasks: Build the current prototype in use in Zambia, test the performance, and improve upon it. This comes from Jordan's desire to make the cultivator the best product possible. This was the three step definition followed during the 10 week span of this project, and was successfully followed in order to address the need in Zambia for a time and effort saving tool to be used in cultivating and weeding the land.

Background

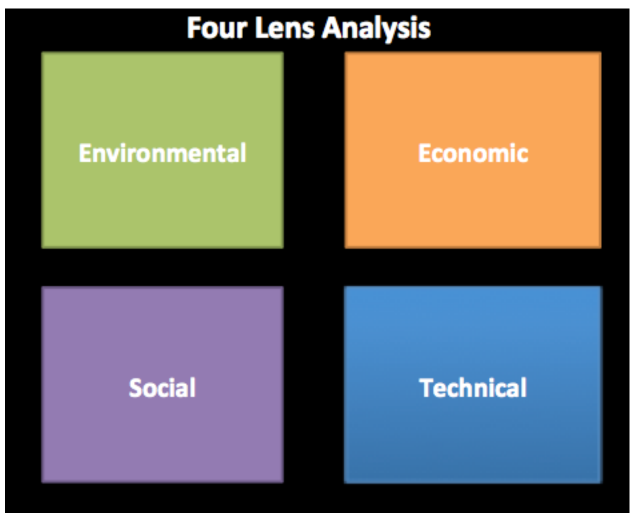

Figure 3: Four Lens Analysis

Construction material analysis

Research was conducted on construction materials of bicycles and agricultural tool blades. It was found that when comparing different materials used to construct bicycles, steel is the best and most appropriate material for use in the bicycle cultivator frame. This is because it is widely available in Zambia in the form of discarded steel bike frames, and offers a combination of strength and durability, having the capacity of be welded on and bent to a certain radius, allowing for more intricate designs ("Construction," n.d.).The best material of construction for the wheel is the most abundant and widely used steel wheel, with a pneumatic rubber tire ("The Wheel," n.d.).While the tire is unnecessary for the bike cultivator, it could be utilized in future improvements to improve grip, stability, and speed. The final key insight obtained from this research was the conclusion that the best material of construction for the agricultural tool blade is some form of metal, due to the abundance of the material and ease of welding ("Encyclopaedia

Britannica: Hoe," n.d.).This bodes well for available materials in Zambia; in a Skype chat with our client, Jordan claimed that the blades used in the current bike cultivators are made from scrap metal, and are easily available and craftable ("Correspondence with Jordan Blekking," 2015).

According to the four lenses analysis, this research fell heavily in the technical lens of analysis, due to the fact it focused primarily on the technical aspect of materials. There was brief discussion over the economic lens, in that the other options for the frame (titanium and carbon fiber) tend to be more expensive and unable to be welded, and therefore not desirable for use in the bicycle cultivator. Our client can use these results to decide which materials to utilize during the construction of future bike cultivators; it allows for a narrowed down decision based on technical material properties, abundance, and a small portion of price associated with each option.

Table 1: Distribution of ruminant livestock ('000) in the different provinces of Zambia *Source: (Aregheore, 2009)*

Provinces	Cattle	Goats	Sheep
Central	363	195	3
Copperbelt	57	6	3
Eastern	251	125	6
Luapula	11	19	8
Lusaka	75	16	1
Northern	11	15	10
North-Western	58	10	10
Southern	1100	224	11
Western	500	4	-

Zambian Agriculture and the Bike Cultivator

Little is known about the physical properties of the bike cultivator and, according to Jordan, there are only five in existence. This is a crucial knowledge gap because this push cultivator design might prove to be an essential row-crop tool for manual agricultural operations. The purpose of this D-Lab project is to enable use of this cultivator through an optimized design.

New design specifications, including cultivator sweep and handle attachments that are both more rigidly secured and positioned appropriately for ease of pushing, can increase the precision and control of the push cultivator allowing operators to run the tool with greater time and energy efficiency.

Figure 4: Geography and ecological zones on Zambia *Source: (Sustainable Agriculture Research and Education, 2015)*

Zambia's climate favors agriculture with abundant arable land in both the southern and northern provinces of the country (FAO, 2015). However, the main commercial livestock areas are the Southern, Central, Lusaka, Copperbelt and Eastern Province, which are areas of Zambia with disproportionately less rainfall per annum. In addition, these agricultural areas are known for their long tradition of having livestock for draught power as well as access to agricultural inputs such as fertilizers (see table 1). Conversely, the northern and northwestern mountainous and plateau regions (see figure 4) of Zambia receive higher rainfall and there is little to no tradition of keeping livestock for draught power nor is there access to fertilizer. Hence, the bike cultivator emerged as a tool to mitigate the labor requirements of farming in the north and northwestern plateau. It is within these regions that Jordan Blekking and our team of consultants believe the bike cultivator will gain the most momentum and popularity due to the area's tradition of manual labor as the primary source of power in agricultural production.

Conservation Agriculture-Is there a role for the Bicycle Plow?

The concept of the Northwestern Bicycle Plow was inspired by our client's experience trying to promote conservation agriculture (CA) among farmers in his Peace Corps community in Zambia's Northwestern Province ("Correspondence with Jordan Blekking," 2015). Because of this, it is important to understand what the climate in Zambia is concerning CA and whether or not there would be a market for a bicycle plow that could be used to practice it. CA began to be promoted in Zambia during the mid-1990s in response to frequent droughts, and is viewed as a sustainable agricultural technique with the potential to improve soil moisture retention and fertility, increase productivity among smallholder farmers, and reduce food insecurity (H. Nyanga, 2012; Sims, Breen, & Luchen, 2013; Thierfelder & Wall, 2010). Most recently, in 2013, the European Union, FAO and the government of Zambia launched an €11 million, four-year CA program aimed at improving the production and productivity of over 300,000 smallholder farmers throughout the country by encouraging its adoption (Roest & Ogolla, 2013).

There are two methods of CA being promoted currently. The first and most basic approach to CA is to use a hand or "chaka hoe" to dig a series of planting basins in rows along the farmer's field. Into these basins, he or she would place seed, along with fertilizer and lime, if necessary (Sims et al., 2013). Smallholder farmers without access to animal draft power have been encouraged to practice this method. While extremely labor intensive, CA has had the effect reducing the amount of time women spend on land preparation because less of the soil is turned over, and traditionally tilling with a hand hoe is considered women's work. CA also enables women to better spread out the work of land preparation since it is shifted to the dry season and can be completed over a longer period of time (Maal, 2011). The second method of CA can be done by either ox-plow or tractor, but involves strip tilling of the field, which is where only the area to be planted is disturbed. The rest of the field is left untouched. These strips are opened up once in the dry season and again at the start of the rains. Additionally, the use of a precision planter that can apply both seed and fertilizer is highly encouraged (Sims et al., 2013).

Given the two CA methods currently being promoted and practiced, it is clear that there is a gap when it comes to improving labor efficiencies for those farmers who do not have access to animal or mechanical draft power. The Northwestern Bicycle Plow could fill this gap by allowing farmers to strip-till their fields using their own manpower. While not as efficient as having an ox or tractor, it could still serve as an important stepping stone for improving the productive capacity of smallholder farmers, who without access to other labor saving technologies, would otherwise be unable to do so.

Methodology

Our client clearly expressed the necessity for design optimization, but before we could begin to offer any improvements we had to start from square one; which included clarifying any confusion or inconsistency with terminology. What Jordan originally designed and what we built in D-Lab I is not a plow but rather a cultivator, which is used for weeding and bed maintenance.

The bike that we used for our prototype was purchased from the Davis Bike Collective in Davis, California. We spoke with experts, both at the Bike Collective and with experts from the UC Davis Farmshop, including Raoul Adamchak and Jason Graff, with regard to the specifics of the bike frame: material, size, weight, height of the push bar to optimize pushing force along both the vertical and horizontal planes, wheel diameter/size, etc.

Our prototype used a 26" wheel diameter, which the experts at the Davis Bike Collective indicated was the international standard and most common size that would be found in Zambia. Following, the bike was dismantled and inverted (as seen in Figure 5). The handlebars were welded in place for rigidity and the seat post was salvaged and used as the shaft. A neck-like attachment was welded to the shaft so that a variety of blades could be easily attached or removed by the fixing and unfixing of two carriage bolts.

Figure 5: Original Bike Cultivator frame *Source: Dropbox photograph shared by Daniel Quinn*

Once fabrication of the bike cultivator was complete, we were ready to perform our field experiments. We used a 9 x 1/4" Duckfoot Sweep that was operated at a recommended depth of 1" to 2" (2.5-5 cm) for best weed kill, highest moisture retention, and minimum force requirements (i.e. the deeper the sinking-in the higher the resistivity force affecting the Duckfoot Sweep in the horizontal plane (Kabwe & Donovan, 2005; Ríd, Abatka, & Eljak, 2004).

Results

In order to achieve a fair comparison, a collection of tests were completed with both The Green Machine and an average hand hoe. The most common hand hoe used in Zambia for cultivation is the short handled hoe (Sims et al., 2013), and therefore would want to be utilized in order to make the comparison more applicable. However, we did not have access to a short handled hoe; the only thing at our disposal was a long handled hoe. To make matters worse, the handle broke when used, and as a result, the hand trials run during our tests were completed using only the blade of the hoe. This would cause greater strain for the person using the blade, as well as a longer time necessary to cultivate, and was a definite restriction during tests.

Table 2: Size comparison of sand, silt, and clay *Source: (Whiting et al., 2003)*

Name	particle diameter
Clay	below 0.002 mm
Silt	0.002 to 0.05 mm
Very fine sand	0.05 to 0.10 mm
Fine sand	0.10 to 0.25 mm
Medium sand	0.25 to 0.5 mm
Coarse sand	0.5 to 1.0 mm
Very coarse sand	1.0 to 2.0 mm
Gravel	2.0 to 75.0 mm
Rock	greater than 75.0 m (~2 inches)

Another restriction that had to be dealt with was the soil available for testing. The soil used for testing was Yolo sandy loam, which is 54% sand, while the soil primarily found in the northwest region of Zambia, where we expect to find the highest demand for this technology, is clay loam (Sustainable Agriculture Research and Education, 2015). From table 2 above, the size of sand, silt and clay particles can be seen. Note that clay particle diameter is extremely tiny compared to sand of any classification, and therefore tend to be feel sticky when touched. Due to the strong physical properties of clay, a soil with only 20% clay particles behave as sticky and gummy. Furthermore, clay or clay loam soils resist breaking, while coarse texture soils, such as sand or loamy sands, break with slight pressure (Whiting, Wilson, & Card, 2003). It is because of this that the sandy loam in which the tests were run are biased; the clay loam found in Zambia would be more difficult to cultivate and the bike cultivator time would be different when implemented on such soil.

Despite these restrictions, a slew of tests were completed both with The Green Machine and hand hoe blade. Three tests were completed by each member of the bikultivator team for both The Green Machine and hand hoe blade. These tests were then averaged and reported as average time to cultivate the available 200-foot plot of land. The results for a simple comparison between average hand hoe blade and Green Machine times are shown below in figure 7. Note the vast aesthetic difference that can be seen. The average time for the three members of our team to cultivate the land with handle hoe blade was 15 minutes, while the average time for The Green Machine was 57.5 seconds. From this, it can already be concluded that from a purely time basis, the bike cultivator is the more efficient method of cultivating, working 15.6 times faster than hand hoe blade cultivating.

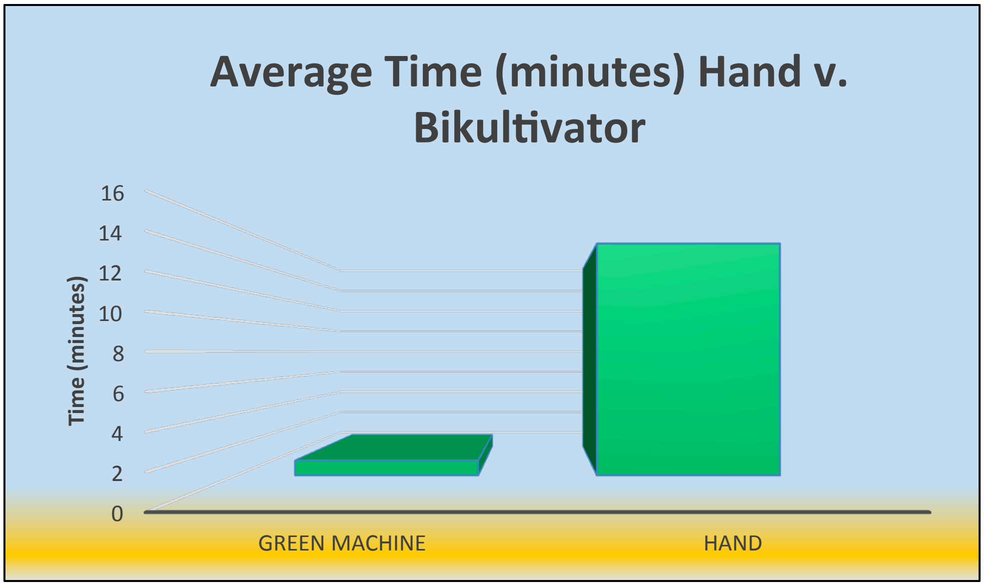

Figure 6: Comparison between average time to cultivate with hand hoe and The Green Machine

Following this, further analysis was completed to compare each member of team bikultivator's times with The Green Machine in order to conclude differences of performance based on gender and height. These results can be seen from figure 8 below. The shortest time was 47 seconds, belonging to Gabriel, the middle time achieved by Tony was 58 seconds, and Elyssa attained the longest time at 67 seconds. Therefore, the longest time belonged to the female member of our team. However, it cannot be said that this is because she is female for two reasons: First, Elyssa was the only female to participate in the testing, and second, these results could have been coincidental. If a solid conclusion is to be drawn on gender differences using the bike cultivator, there would need to be a larger sample size of an equal number of male and female testers, with tests run more than just one day. The same can be said about the differences in height; while Gabriel and Tony happened to be above six feet tall (6 foot 0 inches and 6 foot 2 inches for Tony and Gabriel, respectively), Elyssa was 5 foot 5 inches. These are only three different heights to compare and cannot be used as a solid conclusive evidence without more to compare. Therefore, while there is a difference between testers' times based on gender and height, more planned tests must be completed in order to make an educated conclusion. However, it can be said that even for all three testers, the time necessary to cultivate the plot of land was significantly less for The Green Machine when compared to the hand hoe blade.

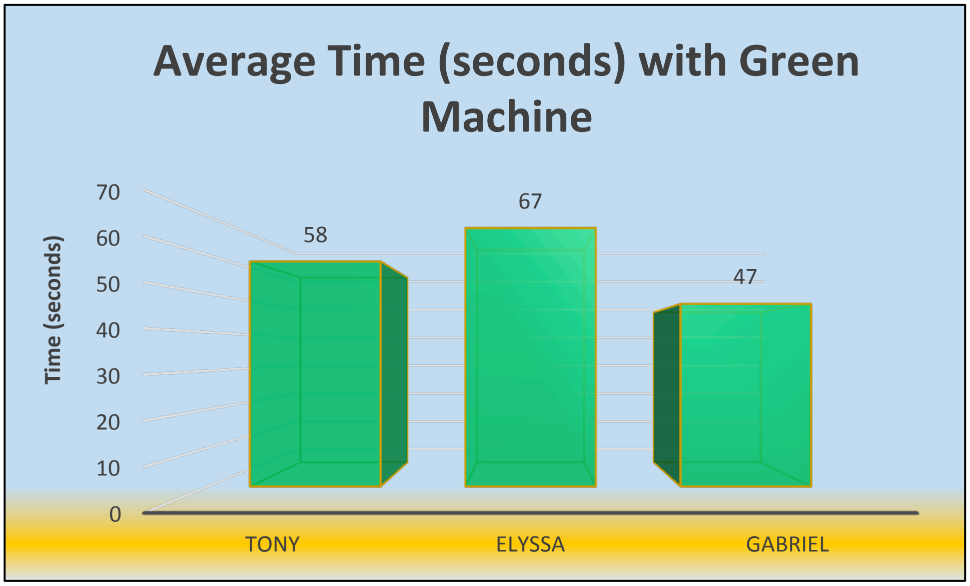

Figure 7: Comparison between three team member's times on the Green Machine

The final conclusions to be drawn from the results are easily seen by viewing the figures above: The bike cultivator saves an immense amount of time for those working in the field. These results have caveats associated with them, such as soil and hand hoe differences, but from a purely time based comparison, the bike cultivator saves time in the field. Further tests must be done in order to further analyze the differences between the operators of the bike cultivator, with improvements implemented in future work at the design level. The client, Jordan, can greatly benefit from these results, if only from a purely numerical standpoint. When variables such as length of land, type of soil, and tool utilized are fixed, it was shown that the bike cultivator saved time when compared the using a hand hoe. These results can be used as concrete evidence of the time saving nature of the tool, and with more appropriate, in-depth tests being completed in the future, Jordan can decide about the next move in terms of disseminating the tool to the people of Zambia.

Recommendations

There are a number of things that we recommend be looked into as this project moves forward. For one, further research should be conducted on whether or not blade size could be optimized based on soil type. The resistivity of the duckfoot sweep is mainly influenced by soil characteristics, particularly type, moisture and compaction (Ríd et al., 2004). Future work should explore ways to circumvent these parameters, which are directly proportional to the labor intensity of soil cultivation. Since it may be difficult to emulate soil conditions of Zambia here in Davis, it will be necessary to ensure the versatility and rigidity of the bike structure, shaft, and adaptability to a variety of sweep designs, including size, shape and tilt. Furthermore, there could be possible trade-off between varying blade size and labor requirements. For example, a smaller blade may be better suited for more clay heavy soils, but this might necessitate additional passes and increase the labor requirements. The labor saving efficiency of such changes will have to be explored.

Figure 8: Completed Bike Cultivator (The Green Machine)

An additional issue that was both presented by our client as well as personally experienced during our own field tests was the difficulty in keeping the bike cultivator straight while pushing it up and down the rows. This is because large clods can easily dislodge it. Yet, in order to be a useful tool, farmers would need it to maintain a straight line so that they can keep orderly fields. A possible improvement could be to reinforce the frame to make the bike cultivator heavier and thus less easily dislodged. However, this would have implications on ease of use and portability around the field, which would need to be explored.

While our tests only looked at the application of this technology in cultivation, due to the origins of the design, it would be important to test its ability to actually plow a field. For the bike plow to be used in conservation agriculture it would need to be able to break the hardpan, which in Zambia is approximately 15 cm deep ("Correspondence with Jordan Blekking," 2015). With a chisel blade attached, instead of a duckfoot sweep, tests should be run on whether or not the plow could exert enough force to break the hardpan, and if any sort of frame and/or shaft reinforcement would need to be made. If these tests are successful, then we believe there would be a market and even the possibility to ally with the efforts to promote conservation agriculture, currently underway in Zambia.

Along the lines of testing out the design with a chisel blade rather than a duckfoot sweep, we recommend that future work should look into the design of interchangeable implements. Such an improvement would broaden the scope of work that could be done with this technology. In relation to adjustments in the implements, future design improvements should also investigate if the height of the handlebars can also be adjustable. An ergonomic study could be conducted, which looks at what the appropriate ration should be between a person's height and that of the handlebars. Another area to explore in seeking to improve the design is wheel diameter. The optimal horizontal and vertical plane forces are greatly influenced by the size of the wheel – too big and the cultivator blade will barely scratch the surface while a wheel that is to small will result in increased labor intensity due to forces lost along the vertical plane. Therefore, a variety of wheel sizes should be tested for each implement.

Process Reflection

Upon completion of the project, there were numerous things that went well, but just as many things were challenging. One of the things that went well was our group's ability to work effectively together. Every single meeting between team Bikultivator was productive, free of judgment, and ended by giving each member a fair split of work to be completed. Another thing that worked well during the process was our team's willingness to give time to the project. We all understood that in order for a product that was more than "just sufficient" to be completed for Jordan, we would have to meet regularly, work around each other's schedules, and give 100 percent. A third thing that went well was the free flow of information between our client and our group; from redefining the scope, to constructing, to future improvements, there was rarely a hiccup experienced in information shared during the process.

That being said, there were a few things that were challenging during the process. First, while our team was willing to meet around each other's schedules, there were times where it would have worked more efficiently if we were able to meet at more agreeable times. Another thing that was challenging was the noticeable lack of shop experience between our group members; none of us had welding experience, and we all had very little experience working in a shop in general. To overcome this, we requested help from Kurt Kornbluth and Steven Wiryadinata to assist in welding and general shop tasks, which proved very successful thanks to their help. A final challenge we had to overcome was time. Ten weeks was a very short amount of time when working with a client overseas and doing something as large as constructing, testing, and improving upon a prototype agricultural tool. Keeping our heads down and committing necessary and available time to the project, we were able to complete everything we set out to do.

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Appendices