Tracie Dang
Mashi Noguchi
Dagan Trnka
6/8/15

Forage Chopper for Silage Production
Sabana Grande, Nicaragua

Tracie Dang
Mashi Noguchi
Dagan Trnka
6/7/15
D-Lab II Spring 2015

Tracie Dang
Mashi Noguchi
Dagan Trnka
6/8/15

Table of Contents

Tracie Dang
Mashi Noguchi
Dagan Trnka
6/8/15

Meet the Team!

Tracie Dang

I am a fourth year undergraduate student majoring in Animal Biology and minoring in Global Disease Biology. I have always had the interest in community health and development especially when it involves veterinary health as well.

Mashi Noguchi

I am a third year undergraduate student majoring in Civil Engineering. I am interested in making an actual difference in communities who need it from an engineering approach.

Dagan Trnka

I am a fourth year Mechanical Engineering Undergraduate Student. I have had an interest in appropriate technology solutions since I started school and my consequent involvement with the UC Davis Chapter of Engineers Without Borders.

Tracie Dang
Mashi Noguchi
Dagan Trnka
6/8/15

1. Design Brief

Our team is working with a client named Hilario Lopez, who is a farm leader and vet promoter, from a small rural community called Sabana Grande in Nicaragua to help alleviate the malnutrition of small farmers' cattle. We are doing so by incorporating a labor-saving mechanism to cut forage for silage (made from fermented crop residues) by implementing a forage chopper to help facilitate the silage production process.

Currently, there are two main problems within the community. First, the small farmers' cattle in Sabana Grande are especially malnourished during the dry seasons between November - April due to the scarce land with most pastures unavailable to graze on. Second, Hilario promotes silage as an alternative food resource for the cattle during the dry seasons, but unfortunately the community is only cutting the forage needed for silage production by hand with one machete. Thus, this poses a huge manual labor cost for the small farmers to produce silage, so this is why we are designing a forage chopper for the community.

2. Design Methodology

2.1 Chopper Design Criteria

Before deciding on what specific chopper we will design as our prototype, we formulated criteria that both favor our client's needs and the Sabana Grande community's needs overall. Here are the following criteria including the metrics on how we will measure each step shown in *Table 1*:

Criteria	Metric
Mobility	Qualitative
Quality of Output	Length (<2cm for forage)
Cost Efficiency	cost/weight of forage (kg)
Optimal Throughput	weight of forage (kg)/time (hr)
Manufacturability	Qualitative

Table 1. Shows our Chopper Design Criteria with metrics included.

1. *Mobility*

This is a qualitative trait which Hilario takes as one of the main important features of the chopper

2. *Quality of Output*
    a. For the forage output, ideally it should come between 1-2 cm lengths in order to make silage
3. *Cost Efficiency*
    a. Ideally should have the most affordable cost/kg of forage which the chopper creates
4. *Optimal Throughput*
    a. Should produce the most kg of forage/hour
5. *Manufacturability*
    a. System has to be low in cost in terms of resources and time and the capability to build the system in terms of skills and tools must be present

2.2 Design Method

Moving forward after determining our design criteria, we examined prior art of industrial choppers, homemade choppers, and studies on chopping mechanisms including different choppers that have been implemented in developing countries and we identified three main subsystems which we see as important for a forage chopper: 1) Feed and Catch Hoppers; 2) Chopping Mechanism; and 3) Power System. These three subsystems are largely independent of each other: i.e. the chopping mechanism doesn't change for whether it is powered by an internal combustion engine or by an electric motor. Please refer to *Figure 1* to view how the three subsystems come together to make up the forage chopper system.

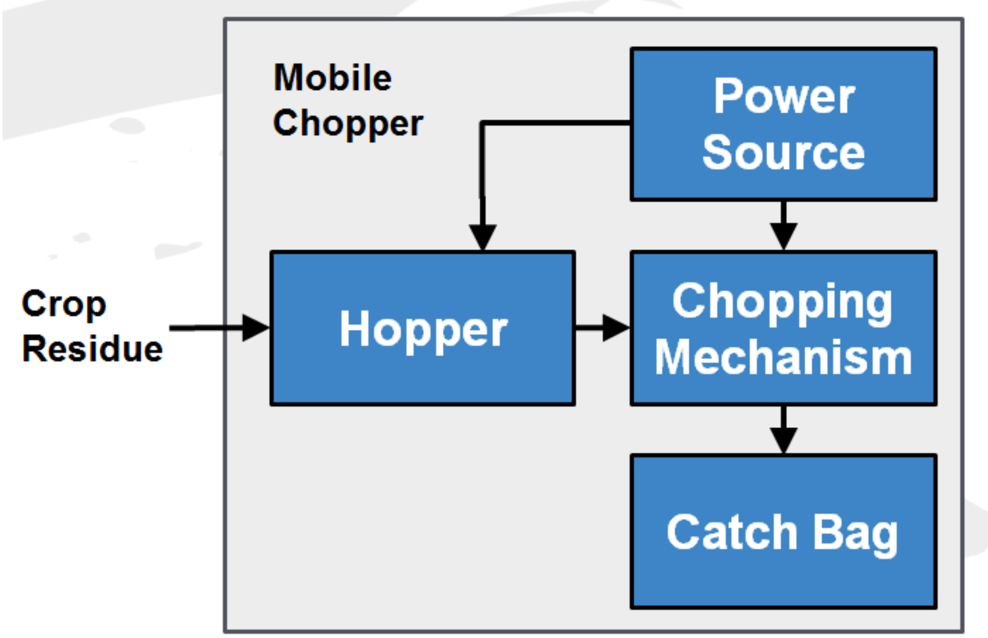


Figure 1. The three subsystems come together to make up the forage chopper system.

An additional tool we used to help identify different designs was finding which designs optimized one of the components to our design criteria. For instance, when we looked at bike-powered choppers, we knew this design optimized for the low cost component of our design criteria, but we knew this type of design was not a top choice for our client because he wanted something diesel or gasoline powered system. Thus, as we further recognized how some designs optimize one or two components in our design criteria but tradeoff lacking the other components, we knew we had to prioritize which component in our criteria we take as our top choice and go from there.

2.3 Design Direction

More specifically, after we identified these three main components needed for a forage chopper, we then favored this system towards our client's needs and to what is most sustainable for the Sabana Grande community by applying our Chopper Design Criteria to different types of choppers and analyzing what design works best. After vigorous prior art research and analysis, this led us to choose the lawnmower as our design direction for a forage chopper, which came from favoring our Chopper Design Criteria the most. Plus, due to serious time and money constraints, we knew this most ideally optimizes for the manufacturability component from our design criteria by us retrofitting the lawnmower rather than starting from scratch and building a forage chopper. Please refer to *Appendix 1* to view a visual image of the lawnmower we used as our prototype.

2.4 Design Components of the Forage Chopper

In terms of applying our three main subsystems into our lawnmower design, we described how we did it in detail down below:

Hoppers:

We identified how it is important for a forage chopper to have a funnel-shaped hopper to facilitate ease of feeding forage into the chopper. We will have forage feeding from the top going downwards into the chopper going towards the cutting department of the forage chopper. As for the exit hopper, it was recognized that an easily removable, flexible bag which allowed air to pass through, but not forage was needed. Please refer to *Appendix 6* to view an image of the forage bag attached to the exit output hopper with a bungee cord.

For the hopper, it was only made from PVC pipe using a pressured 4" diameter pipe, a pressured 4x6" reducer-coupling, and a non-pressured 6x8" diameter reducer-coupling. The whole hopper is 3' 9" in length with it being attached to the top of the lawnmower with a PVC connector by drilling a 5" diameter hole in the lawnmower and connecting the two with nuts and bolts. We also used PVC primer and cement to ensure connection between the 4" diameter pipe and the 4x6" reducer-coupling and also between the 4x6" reducer-coupling and the 6x8" reducer-coupling. In *Appendix 2* it shows a visual image of the hopper in its final form connected to the lawnmower and painted black. Note as a safety precaution, we made sure the length of the hopper is long enough so a person cannot reach their arm in far enough to reach the blades inside the chopper.

In addition, we also built a wooden plunger that is around 2” in diameter which can help push forage down from the hopper into the cutting department of the chopper. As a safety measure, we made sure to attach a 4” diameter circular wooden flat base to the end of the wooden plunger to prevent it from being damaged by reaching the blades inside the chopper. To double the safety measures, we also attached a rectangular flat piece of wood perpendicularly to the top of the wooden plunger to prevent the plunger from falling further into the hopper as seen in *Figure 2*.

Figure 2. Depicts the main entering hopper and the wooden plunger

Chopping Mechanism:

The hopper was the first component of the system worked on. Initial tests of the top-fed modified lawn mower taught us that the blade needed to be modified so that it was made to cut plant material being fed from the top. More than this, to prevent the plant material from spinning with the blade in the cutting compartment without being cut, we realized that a counter-blade similar to those identified in our prior art research would have to be implemented in addition to modifying the mower blade.

The fundamental blade design came from a prior art study of a review in forage chopping (O’Dogherty, 1982). Essentially the mower blade was re-designed to accommodate the cutting of thicker forage from the top down. A typical mower blade is designed to cut grass from the bottom up and since the motor only spins in one direction the blade inevitably had to be inverted to angle upwards (See *Appendix 3 and 4*). There were two important blade parameters that were considered: the blade angle and the rake angle as defined in *Figure 3*.

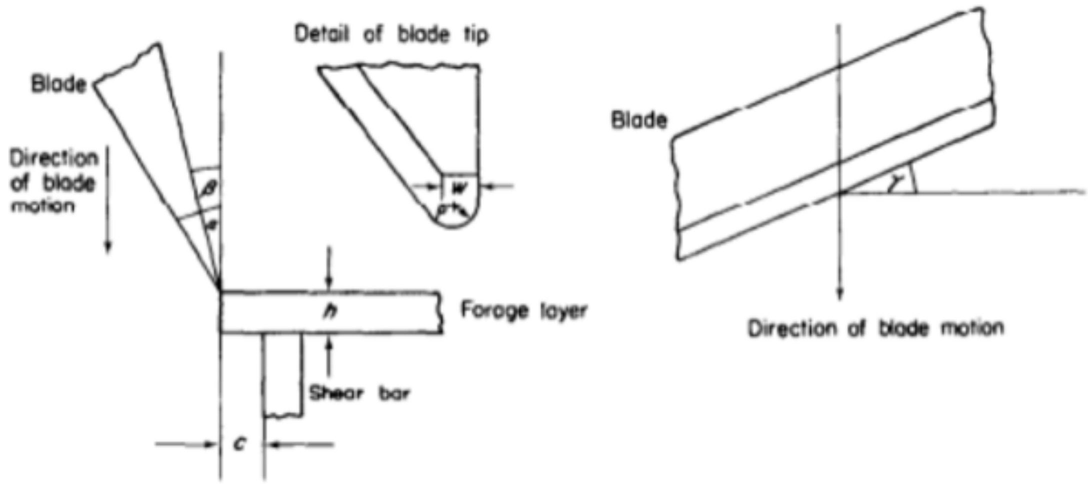


Figure 3. The blade angle is given by and the rake angle is given by .

Literature suggested that the optimal blade angle to be 30-40 degrees and the rake angle to be 10-20 degrees. The blade was bent through a process called annealing where the metal was heated up using a flame torch up until it was red-hot (*Appendix 7*). A simple vice grip and a wrench was utilized to mechanically twist the blade to its intended angle. The rake angle was achieved by using the angle grinder both for cutting and getting the sharpened edge (Figure 4).

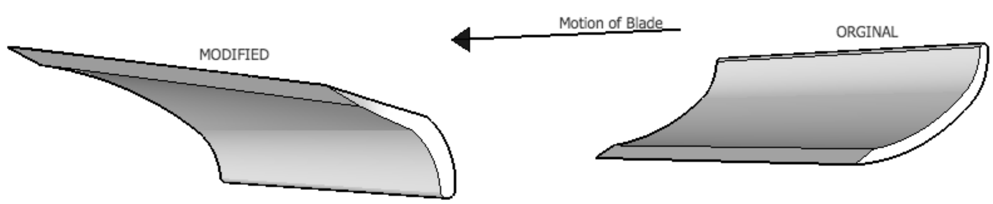


Figure 4. From the original blade (Right) to the modified blade (Left)

As for the stop, the purpose of including this in addition to modifying the blade was to integrate the anvil action found in disc blade choppers identified through our prior art research (Robinson, M., 1989). Such anvils can be seen in *Figure 5*.

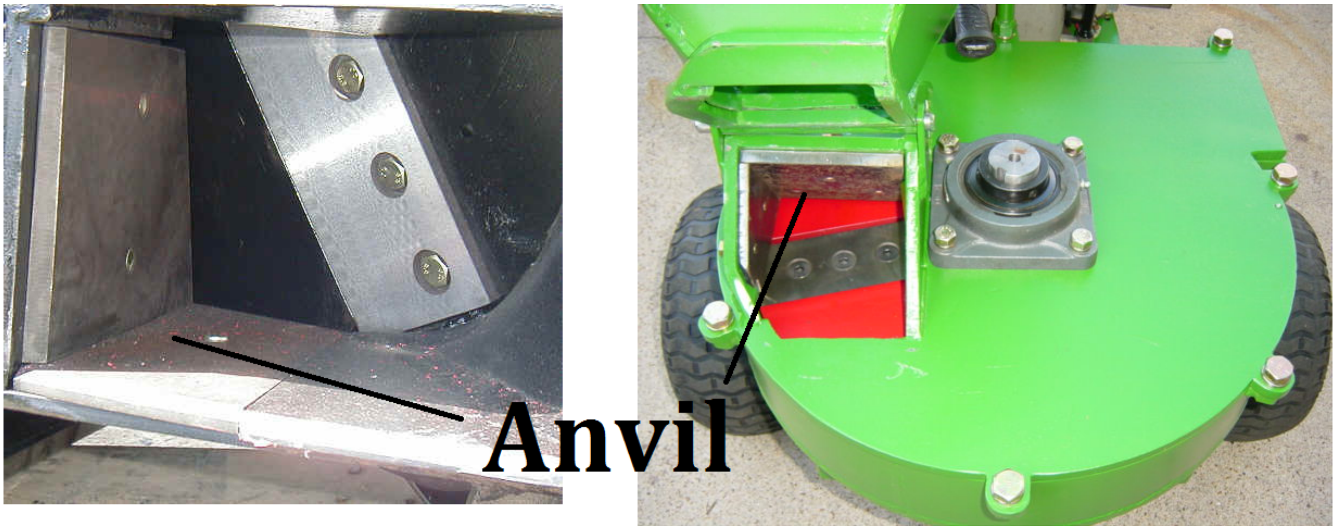


Figure 5 . The anvil as found in wood chippers which operate with a disc blade. (Images from Iowa Farm Equipment(left) and Steve Bedair (right))

In addition to implementing the anvil into our design, we also decided to turn it into a counter blade so as to supplement the stopping function of the anvil with a scissoring action. The anvil-disc blade design is focused on chipping wood, not slicing non-woody plant material which is what we needed to focus on. Once finding that a counter-blade or a stop was needed within our design, the physical dimensions and specific features of the stop were then identified. To ensure that the stop was effective, it was made long enough so that it encompassed the whole cutting area of the modified blade. In addition, the stop was made in such a way that it could be raised and lowered from outside the cutting compartment. The ability to control the height of the stop was identified as an important component of the prototype design because it would allow us to test how the the distance between the stop and the mower blade effect the length of the cut material. The need to adjust the stop from the top came from the need to make it both convenient and safe to do so. *Figure 6* illustrates the concept and provides a cross sectional display of the mechanism and shows how this system was implemented in reality.

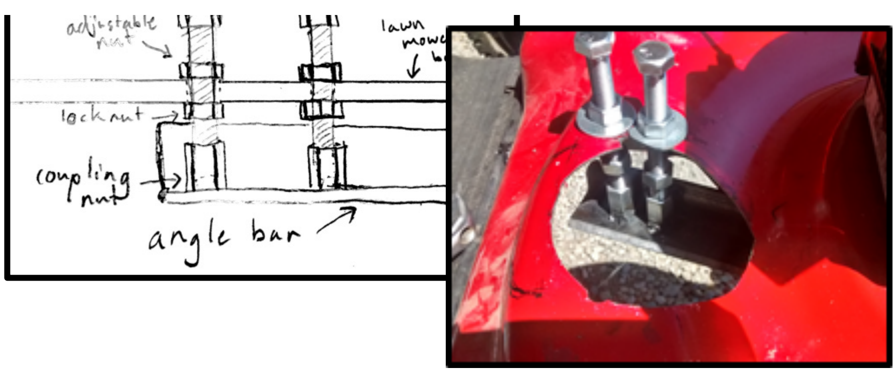


Figure 6. Design concept of stop and implementation of it

The cutting body of the stop was made from mild steel angle bar and the height control mechanism was made with two ½"x5" bolts, two 1 ¼" long coupling nuts, and four nuts. The coupling nuts were welded onto the angle bar and the two nuts that are on the cutting compartment side of the bolts were turned into lock nuts by ovalizing them. Through tightening and loosening the bolt and the nut on the outside of the cutting compartment, one can control the height of the stop. As for the cutting body, a 35-45 degree cutting edge was ground on one of the edges of the angle bar. The angle of this edge was chosen for the sake of manufacturability: the fact that the material we were working with was angle bar prevented us from easily achieving the more acute angled cutting edge identified as desirable as discussed above for the mower blade. One can find more images of the blade and stop mechanism of the mower in Appendices 3 and 4.

Power System:

In deciding to retrofit a lawn mower, we were also deciding to use the power system already available with the system. Though the client desired a system powered by diesel, we decided to continue with the choice of the 4-stroke gasoline engine found with the lawn mower so that we could focus on the component of the system we saw as more critical: the chopping mechanism. More than this, we reasoned that an engine powerful enough to cut grass and weeds effectively should be powerful enough to cut the forage we were planning to feed it.

The engine on the mower is a Briggs and Stratton 500 series 4 stroke SI engine capable of 5.00 ft.-lbs. gross torque at 3060 rpm. With a quick conversion, this amounts to a 2.93 hp engine. The blade is directly coupled to the engine and will stall if the blade is unable to move. Other features of the engine is that there is a throttle which can allow the user to moderate the power output and fuel consumption of the engine. More than this the mower comes with a brake which must be engaged for the mower to run. If this brake is released, the engine cuts out. This is a safety mechanism which prevents the mower from being run if the operator is not actively holding down the spring loaded brake lever. An additional safety precaution taken with the engine is the disconnection of the spark plug when the machine was not being run so as to allow safe access to the cutting compartment. Refer to *Appendix 5* for images of the engine used.

3. Results

The cost of producing a kg of chopped forage can be determined from the experimental data as seen in *Table 2*:

Table 2. Summary of the testing results conducted with three different types and sizes of forage.

Stalk Size	Throughput (kg/s)	Fuel Consumption
Small (5mmØ)	0.3*	35ml/kg
Medium (15mmØ)	0.5*	16ml/kg
Large (25mmØ)	1.5	20ml/kg

*Throughput mass adjusted for dry base mass assuming moisture content of 50%.

The current price of gasoline in Nicaragua is US$3.92/gallon (Central America Data, 2015) . The fuel consumption to cut the large stalk diameter forage was 20ml hence the cost of fuel in Cordoba to produce a kg of chopped forage is: (USD to NIO, June 2015).

$$\frac{US\$fuel}{kg} = \frac{US\$3.92}{gal} \times \frac{0.0053gal}{20ml} \times \frac{20ml}{kg} = \frac{US\$0.21}{kg} = 6\ Cordoba\ /kg$$

Recalling that each cow requires 1386kg of worth of chopped residue to keep them fed throughout the three of the driest months and with 60 cows to be fed, the community needs to produce at least 84,000kg of chopped residue a year. This will come out to be 504,000 Cordoba per year. This roughly translates to around 10% of their combined annual community expense (D-Lab 1 Final Report).

4. Conclusion

Testing our system taught us a great deal about it. We discovered an additional operation mode, found that the length of cut of the forage is independent of the stalk diameter of the forage being cut, and that the chopper is most effective at cutting long, thick stalks with little branching nodes and leaves. When operating the chopper, we discovered that when the output is closed off, the plant material within the system is chopped into a finer product. The tradeoff of this operation mode is that it increases the amount of fuel used to produce the chopped forage because the throughput is lower, but the fuel consumption is roughly the same.

That the chopped length is independent of the stalk diameter of the forage material we feed the system is an important find for this project. When testing the system, we were unable to use the plant material which would be used in Sabana Grande, Nicaragua. The fact that the length of the chopped material is independent of the stalk diameter and species of the plant allows us to extrapolate that the cut length of the plant material to be used in Sabana Grande, Nicaragua will also be the same.

It was also found that in order to take the most advantage of the system, thicker stalked plant materials should be used. Additionally, before using these pieces they should be stripped of any branches and leaves to prevent the material from getting jammed in the hopper. When testing with the thinnest stalked material -- which also happened to be the bushiest -- it was found that the material kept getting caught on the ledge produced by a joint of the PVC hopper. To alleviate this, tape was put over this section to smoothen out the edge of the joint. The addition of tape over the ledge helped alleviate the issue of jamming, but it did not rectify the issue entirely.

One final note on identifying components of our design that went well is the process with which we designed the system. From conversations with our client we were able to identify the design criteria around which we were going to identify our design. From the identified design criteria, we identified several designs and then proceeded to evaluate them by examining prior art and referencing our target values for the design criteria. The mower design was selected for the reasons mentioned previously. The iterative nature of design was soon recognized afterwards. Through initial testing, we found we needed to modify the chopping mechanism. Through the fabrication process, we found that we needed to modify certain aspects of the hopper such as how it was fastened to the mower. Finally, our testing of the complete assembly taught us how to access an additional operation mode of the chopper.

6. Recommendations

6.1 Improvements

There are a few improvements we noted to do for short-term and long-term goals to improve the efficiency of the forage chopper. First for short-term goals, we noted how we need to find a more sophisticated way to attach the catch bag to the output hopper rather than using only a bungee cord to hold the bag onto the output hopper. Plus, we also need to find a more sophisticated, high quality catch bag as well since we are only using a chicken feed bag as our temporary. In addition, we need to find a way to cover the corners between the base plywood of the lawnmower and the cutting department due to having some forage being loss and trapped between these corners, which can also clog the cutting department and negatively affect the forage output.

For our long-term goals of improvement, we plan to analyze other engine power systems like solar-powered system for our forage chopper, which can be more suitable for the Sabana Grande community having a “solar culture” and to reduce the maintenance cost as much as possible (greenbiz.com). We also want to further test the chopping mechanism of the chopper by adjusting the blade stop to different heights or taking out the blade stop completely to see if this overall affects the cut of the forage output lengths.

6.2 Moving Forward

After D-Lab II, we are officially traveling to Nicaragua to meet Hilario and the rest of the Sabana Grande community mid-June. For preparations, we plan to put together an English and Spanish version of a 1-2 page visual outline on how our forage chopper works for the community to review and also provide a poster of this visual outline as well in Spanish. Furthermore for preparations, we plan to work on our short-term goals of improvement (as stated in 6.1 section) as soon as possible. If we cannot find a higher quality catch bag and cover up the corners between the base plywood and the cutting department in time, we will then purchase a catch bag and cover up the corners in Nicaragua instead when we go there mid-June. In regards to the forage chopper, we plan to bring it to Nicaragua and provide it for the community to test out hands-on if it is compatible with their silage production process. Ideally when we are in Nicaragua, we plan to learn from the community as much as possible about their cattle, silage production, etc. and help us tackle other long-term goals of improvement to further improve the efficiency of our forage chopper.

5. Project Reflection

Overall our team was very satisfied and excited on how our forage chopper can effectively cut forage with an output of ideally 1-2 cm in length which was needed for silage production. Despite our conflicting schedules with our team members, the different technical building experiences, and the inability to communicate with our client Hilario speaking Spanish, we still overcame these obstacles through effective communication with each other, commitment to the project and our client, and the willingness to compromise.

In terms of the forage chopper, we are very excited how our prototype works and how it successfully favors our design criteria including Hilario's needs and the community's needs overall. However, throughout the course of D-Lab II, we were very constrained on time and money which led us to decide to retrofit an existing design, the lawnmower, rather than creating a forage chopper from scratch. Before we officially decided to retrofit the lawnmower, we felt very pressured to pinpoint down a certain design which can satisfy Hilario, be most sustainable in the Sabana Grande community, and can realistically be completed within a timespan of ten weeks. Due to us also having little knowledge of small forage choppers, the most intense and frustrating times was when we were researching, analyzing and communicating with people who had different types of forage choppers with different power systems.

Eventually after vigorous research, we finally understood and saw a similar trend of what each chopper had, which led us to develop a general design method (which we broke down into three main subsystems) of how an efficient forage chopper should look. From then on, we further understood how a forage chopper should have an entering and exiting hopper, a chopping mechanism and a power system, and led us to create ways on how to use the most affordable and sustainable resources available to design these components for our prototype within a $250 budget. We also took into consideration on using resources for the chopper that are most available in the Sabana Grande community.

Over time, we became more confident on how we could design our hoppers and the blade stop, and re-design our lawnmower blade which ultimately brought together our forage chopper that can successfully chop forage to ideal lengths of 1-2 cm for silage production. It should be stressed however that the construction of the retrofitted lawn mower prototype was more an exercise in developing an effective chopping mechanism than it was for creating our clients ideal chopper. As stated before, our team was driven to choose the lawn mower design due to the manufacturability design criteria. With this being said, the prototype manages to meet the needs set by our client and at the very least, has taught us a great deal about chopping forage. We are confident that our project is going towards a positive direction to satisfy our client and to help the Sabana Grande community alleviate the malnutrition in their cattle.

7. References

Bedair, Steve. *Chipper Knife & Anvil View.* Photograph October, 2005

Central America Data. (2015, May 25). Fuel Price. Retrieved June 7, 2015, from Central America Data.com Business Information: http://www.centralamericadata.com/en/search?q1=content_en_le:%22Fuel+price%22&q2=mattersInCountry_es_le:%22Nicaragua%22

Guevara-Stone, Laurie. "Solar Innovation Gives Nicaraguan Community a Brighter Future." GreenBiz. N.p., 13 Mar. 2014. Web. 5 May 2015. <http://www.greenbiz.com/blog/2014/03/13/how-solar-transformed-nicuraguan-community-grupo-fenix-sabana-grande>.

Iowa Farm Equipment. *Image of Anvil.* Photograph June, 2013

O'DOGHERTY, M. J. (1982). A Review of Research on Forage Chopping . Journal of Agricultural Engineering Research , 27 (4), 267-289.

Robinson, M., "Optimizing Chip Quality Through Understanding and Controlling Chipper Design Characteristics and Other Variables," TAPPI Proceedings, 1989 Pulping Conference: 325-338.

Tracie Dang
Mashi Noguchi
Dagan Trnka
6/8/15

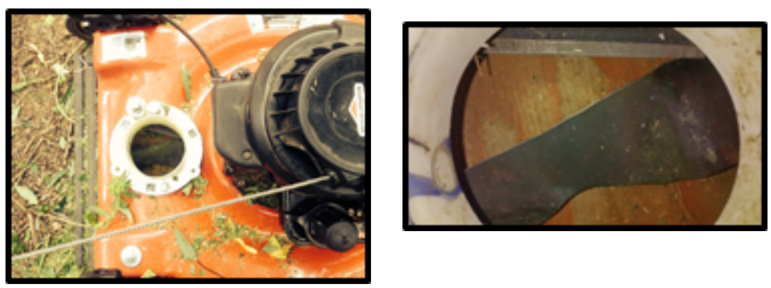
8. Appendices

Appendix 1

Appendix 2

Appendix 3

Appendix 4



Appendix 5

Appendix 6

Appendix 7