Mechanical Harvesting of Leafy Greens on Small Farms

by

Kathleen Kraines

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Mechanical Engineering

at the
Massachusetts Institute of Technology

June 2013

© 2013 Massachusetts Institute of Technology. All rights reserved.
ABSTRACT

Over the last century and a half, farming practices have been revolutionized by the advent of mechanical harvesters, but there is a disparity between available agricultural technology and the technology used in the farm equipment that is affordable for operators of small farms. The harvesting practices for salad greens from small farms is just one example of this disconnect. This thesis is a historical and design study of mechanical salad green harvesters for small farms. The designs consist of a frame with power, cutting and collection systems mounted to the frame. Developing an inexpensive salad greens harvester would help small produce farms in one way, but it is only a step toward the overall transition inventors, entrepreneurs and manufacturers need to make toward equipping small farms with the technology that is already in use on large farms. Many consumers have begun deliberately purchasing from local sources. It would be advantageous for farmers and manufacturers alike if agricultural industries began deliberately addressing the demand from small farms.

Thesis Supervisor: Daniel Braunstein
Title: Senior Lecturer
Table of Contents

Abstract
Acknowledgements
Table of Contents
List of Figures
1. Introduction
   1.1 Agricultural Machinery
       1.1.1 Old Farm Tools
       1.1.2 Powering Farm Equipment
       1.1.3 Mechanical Harvesting
   1.2 Opportunities for Innovation
       1.2.1 The Locally Grown Movement
       1.2.2 A Changing Demographic
   1.3 Salad Greens Cultivation and Harvesting
2. Harvester Version 0.0
   2.1 Background
   2.2 Frame
   2.3 Cutting Carriage and Mechanism
   2.4 Collection
   2.5 Power
   2.6 Performance
3. Harvester Version 1.0
   3.1 Background
   3.2 Frame
   3.3 PTO Specifications
   3.4 Carriage and Cutting Mechanism
   3.5 Collection
4. Summary and Conclusion
6. Bibliography
List of Figures

Figure 1-1: A manually powered EarthWay seeder 11
Figure 1-2: Whippletree sketch 12
Figure 1-3: A machine for weeding 13
Figure 1-4: An old steam engine displayed roadside 12
Figure 1-5: A PTO shaft on a tiller 15
Figure 1-6: Operating angle illustration 16
Figure 1-7: Model of an early Bell Reaper 17
Figure 1-8: Agritourism efforts on a small farm 19
Figure 1-9: Illustration of common salad greens 21
Figure 1-10: Greens harvesting market graphic 22
Figure 1-11: Handheld greens harvesting machine 23
Figure 2-1: Comparison of spinach beds from different farms 25
Figure 2-2: SolidWorks rendering of the harvester’s frame 26
Figure 2-3: SolidWorks model and picture of slotted slider 28
Figure 2-4: SolidWorks rendering of the cutting mechanism 30
Figure 2-5: Collection plenums on the cutting carriage 31
Figure 2-6: Front view of harvester 32
Figure 2-7: Power kill switch on handlebar 33
Figure 2-8: Toggle switches for power to individual systems 36
Figure 2-9: Harvester at 2.009 final presentation 37
Figure 3-1: Three point hitch and PTO 40
Figure 3-2: SolidWorks rendering of three point hitch 41
Figure 3-3: SolidWorks rendering of carriage framework 43
Figure 3-4: SolidWorks rendering of frame and carriage assembly 44
Figure 4-1: Annotated sketch of band saw alternative 45
Figure 3-4: Annotated sketch of potential combine design 46
ACKNOWLEDGMENTS

The author thanks all the instructors, staff and mentors from 2.009, Fall 2012. In particular, the author recognizes Dr. Daniel Braunstein for his commitment to teaching, enthusiasm about the project, and mentorship for the thesis. Additionally, Professor David Wallace and Professor Warren Seering for their faithfulness to assist and instruct. The author acknowledges the hard work and creativity of the entire Yellow Team from 2.009 in 2012 – Fareeha Safir, Daisy Yan Yuen, Steven Carreno, Steven Hahn, Philip Crain, Jay Sircar, Keneth Pinera, Geoff Dawson, Carolyn Coyle, Leslie Meyers, Stephanie Cooke, Conrad Bastable, Justin Colt, Aaron Fittery, Blair Gagnon, Ranjeetha Bahrain, and Eduardo Russian. Thanks to Lauren Hernley for taking photographs.

A heartfelt thank you is extended to Tyson Neukirch and the entire Farm School for their partnership with the project, and Jim Wilson at the Wilson Farms for his hospitality and expertise about farming.

To the faculty and staff of the Mechanical Engineering Department at MIT – thank you for the emphasis place on teaching undergraduates.
1. Introduction

Society today is no less dependent on the produce of the land than it was a few thousand years ago. From gathering wild food stuffs to wide scale commercial farms, the basic principles of collecting what has grown in the dirt has provided the sustenance required to support huge populations of people. The general idea remains unchanged, yet the methods of living off the land have adjusted with the technology of the day. Initial developments in agriculture allowed nomadic peoples to stop moving and live off cultivated land. Today, much of the world’s food is produced on large farms that require a remarkably low number of laborers. Consequently, people can pursue vocations outside of agriculture and still have access to food for their families. Even so, small farms still exist and contribute produce and meat to the fresh market. Owners of these farms may rely on the farm profits as their only income or they may work the farm in their spare time while holding another job. Whatever the nature of the small farm is, it almost certainly under utilizes the available technology. Historically, large farms have been the only farms with sufficient capital to buy the newest innovations in equipment. Innovations in agriculture then centered on large operations, and the technology was not necessarily scaled back to a reasonable price for the small farm. One example of this is can be seen in the harvesting of leafy greens. While the crop is harvested by equipment that costs many thousands of dollars, small farms still harvest their greens with scissors and knives.

1.1 Agricultural Machinery

Mankind’s transition from a nomadic lifestyle of hunting and gathering to a settled agrarian lifestyle would not have been possible without developing tools specially designed for agriculture. Many societies then became strictly agricultural, and everyone’s vocation was closely linked with agriculture. Better farming equipment and practices eventually led to surpluses in food supplies, which granted members of society freedom from farming. People were able to specialize in different disciplines and vocations. Machinery has been continually improved to the point that in some communities, a very small minority of the population is employed in agricultural activities.

In the following sections, a broad overview of farm tools is given. The power source for farming equipment is often the limiting factor in innovation, but the available sources are discussed. Finally, the specifics of mechanical harvesting machinery are discussed.
1.1.1 Old Farm Tools

The first tools used to prepare the land for cultivation were simple wooden constructions. Sharpened edges could cut into the soil, but were worn quickly and had to be replaced often (Blanford). Rocks could be tethered to wooden handles for some uses, but the durability of wooden implements was still a limiting factor. Great strides were made when iron was first used. Wooden implements could be covered in sheets iron to provide sharper points or edges, and greater resistance to splintering and wear. The best early ploughs were wood frames with an iron blade on the front edge. Other tools like rakes and hoes became practical and useful tools when made out of iron because the thin cross-sectional area still had enough stiffness to work the land. With increased land preparation abilities, farmers could grow more. This brought up needs for improved harvesting methods and machinery. Slowly, these implements were developed almost entirely from wood and iron. Iron was not an ideal material for all purposes though. Wheels made out of the metal were sturdy but heavy. In order to travel over soft and malleable ground, the wheelbase had to be quite broad. Rubber for wheels and belts, steel for even stronger and more durable equipment, and improved manufacturing processes enabled some of the greatest changes in farm tools with in the last century and a half.

1.1.2 Powering Farm Equipment

The first tools used to cultivate land were simple implements powered and operated by people. Basic hoes and tillers plows are hand-held tools used to prepare the soil. While these crude devices have been in use for thousands of years, they maintain their relevance and are still sold throughout farming, gardening and hardware stores (Figure 1-1). Exertion and some skill are required to properly operate these tools, and the user is provided with very little mechanical advantage to increase the power they exert. Many other farm implements do incorporate more complex designs to simplify the operator’s labor requirements. Small farms today often still use push seeders. The rotation of one or two large wheels actuates the release of seeds in even increments. An operator stands behind the implement and inputs the only power required to seed a field.
The most obvious drawback of manual equipment is the limited power a person can exert. Humans fatigue which makes them an unreliable source of power. Many of the first more complicated harvesting machines started as draft animal drawn mechanisms. The first reapers are included in these early draft animal powered machines (Winder). Fatigue was still the limiting factor for these machines. Harnesses were developed so that several horses could pull or push the same implement simultaneously. Whippleletree mechanisms used a series of linkages to keep the load evenly distributed among a team or draft animals (Figure 1-2).
The fact remained that working animals could not output continuous power over time. Beasts of burdened were not an economically advantageous source of power either. While machinery requires maintenance including greasing with and during each use, cleaning after use, and repairing or replacing broken parts, draft animals have requirements that must be attended to daily are a constantly recurring expense.

Using the same operating principles as draft animal drawn and human powered machinery yet without the concern of fatigue and with power capabilities orders of magnitudes greater than that provided by man or beast, ground driven machinery hitched to the rear of tractors is used commonly to cultivate land (Figure 1-3). Many ground-driven ploughing, furrowing, and weeding implements have undergone little redesign in the last century as compared with their changes in efficacy. The dramatically more powerful implements that drive them explain this change.
Figure 1-3: This weeding implement works when hitched to a tractor and dragged through a field. The prongs that are shown hanging now dig into the soil and disrupt root systems when the machine is resting on the field. The angle of these prongs can be adjusted to only adjust shallow root systems. For some crops, the machine can be used after planting to kill the shallow weed growth while leaving the deeper crop root systems unharmed.

Today, many pieces of farm equipment use the power take off from a tractor. Attaching to the tractor engine’s shaft, the mechanical energy from the engine can be used to move components of auxiliary equipment. Tillers, seeders, thresher and some harvesters have applied this technology in the field for decades. This is an advantageous power option for most farmers because they are accustomed to tending to their fields with a tractor and farm beds are frequently designed around the tractor dimensions. The use of power take off, or PTO, powered machinery on farms began before tractors had been invented.

In fact, as soon as steam engines were developed for portability and use in agricultural settings, farm machinery began operating with PTO from the engines. One example of an early twentieth century steam engine designed for farm use is shown below in Figure 1-4. The reciprocating motion from an external engine was converted into moving a large flywheel. Belts or shafts were then attached to the flywheel apparatus to power equipment like threshers. Operating such an engine was still laborious. Animals had to be hitched up in order to move the machinery about the farm, and up to two men had to tend the fire and maintain the engine the whole time it was in use. Both fuel and water were required to keep the engine running, which
generated separate hauling demands. The hassle was worthwhile for large farms, and some farms even invested in multiple engines that could stand at opposite ends of a field for ploughing or threshing large tracts of land (Blanford).

In addition to being labor-intensive, having an external steam engine in the fields was dangerous. Sparks could easily escape as fuel was added and set fire to the crops that needed to be harvested. An entrepreneurial farmer in the American Midwest, John Froelich, saw an opportunity to apply the new technology of an internal combustion engine. Strapping a single-cylinder engine onto his steam-powered thresher, Froelich successfully threshed wheat with a “traction motor” in 1890 (Coleman & Burnham). Four years later, Froelich was involved in the start of the Waterloo Gasoline Traction Engine Company. Success came slowly for the company. The Waterloo Boy, the first successful commercial tractor manufactured in the United States did not reach markets until 1902, but the idea of a tractor grew in popularity. Model R of the Waterloo Boy sold well starting in 1914 (Blanford). The company was not the lone manufacturer of tractors even at this time. For example, Charles Hart and Charles Parr had a successful model by 1902 (Coleman & Burnham). Desiring to compete with the appeal of urban
life in the advent Ford's Model-T, Deere & Company decided to expand their agricultural product manufacturing to include tractors. They purchased Waterloo Company in 1918 for $2.35 million and became the largest tractor manufacturer worldwide, where they have remained for most of the last century (deere.com). In 2012, they controlled over 44% of the US tractors and agricultural machinery manufacturing market (Boyland).

As tractors became independently mobile, and began traversing fields, powering equipment remotely with a flywheel and belt became impractical. An output shaft coming directly from the engine was adopted as the new power transmission method. Equipment was hitched to the tractor, and driven by a PTO shaft from the tractor to the machinery. The engine output shaft and the PTO shafts are highly standardized today. A standard shaft consists mainly of two concentric tubes (Figure 1-5). These telescoping components provide a degree of

Figure 1-5: A PTO shaft with a yellow cover extends from this cultivator.
freedom in the distance between the tractor and the machine. Universal joints are attached on either end of the shaft with female mate components that attach to the tractors output shaft and the implement. The universal joint configuration allows the PTO shaft to operate at an angle relative to the ground level (Figure 1-6).

![Operating Angle Diagram](image)

**Figure 1-6:** Illustration of the PTO shaft operating angle.

Consequently, implement design can vary greatly based on performance goals. Additionally, turning the tractor with an implement attached and creating an angle is acceptable which provides greater freedom in operation and ability to turn from one row to the next. There are limits to these operating angles; however, and an implement’s PTO is designed to comply with a very specific set of acceptable operating angles (Kepner, Bainer & Barger). The advantages of PTO power are manifold, but it is important to remember the inherent safety concerns that arise when a very powerful shaft is rotating at 540 or 1000rpm.

Solely electric farm machinery has not been developed on any broad scale up to this point. This has been strongly influenced by the fact that hydraulic and PTO powered equipment is widely accepted among farmers, the procedures for design and manufacturing have been refined over decades, and the standards for such equipment are clearly laid out. Among a consumer group that is notoriously slow to accept change, any manufacturer that tries to produce and sell a fundamentally different line of equipment is assuming a great deal of risk, or so it would seem. However, this year, John Deere introduced a fully electric tractor model at a trade show in Europe. This tractor would not use hydraulic or PTO power to operate attached equipment. Rather, implements would be plugged into the tractor and electrically powered. Developers of agricultural machinery recognize that no electric implements will be manufactured until the tractors to run them are a compelling option for farmers. Coming years could see the advent of fully electric tractors, harvesters, mowers and other equipment gaining a significant portion of the agricultural machinery market. PTO and hydraulic equipment may become obsolete; however, this will not come to pass at an alarming rate. Carefully maintained machinery can last for decades and until electric options come with a compelling lifetime cost
advantage, change-averse farmers will not be inclined to replace the kind of machinery that has served them well with an alternative.

1.1.3 Mechanical Harvesting

Figure 1-7: This image models the Bell Reaper, the earliest effective mechanical reaper, which was first built in 1826. This machine was pushed by a horse and could harvest about one acre per hour, but Bell’s model was difficult to produce and too unreliable to reach large markets (Blanford, ScottishMist.com).

The first steps in developing mechanized harvesting systems were taken in the late eighteenth century and early nineteenth century to address the task of harvesting grains in bulk. These early machines - reapers - gained real commercial success after Cyrus McCormick began to sell a reliable and successful reaper starting in 1840. They relied on horses for power and utilized a scissor mechanism at ground level to cut grain. Additional functions, like threshing, were incorporated which lead to the classification of combine machines. Mechanical harvesting techniques were subsequently developed for an assortment of crops from root vegetables to berries to leafy greens. By the 1970s, most of the fresh market produce and nearly all of the other produce grown in the United States was harvested mechanically (Cargill & Rossmiller).

The most influential innovations in farming machinery; however, have not been the result of better materials and clever mechanisms. The pace of technology in farming did not drastically
change until there was a revolution in power sources. Men and animals cannot provide constant power because they tire. To increase available power, the only option was to increase the number of laborers. By the start of the nineteenth century though, the steam engine had become more than just a novelty and could be manufactured for practical use in many fields (Hills).

1.2 Opportunities for Innovation

1.2.1 The Locally Grown Movement

Within popular culture throughout the last decade or so, there has been an growing resistance to overly processed and distantly grown food. Books, reports and documentaries including The Omnivore’s Dilemma and Super Size Me have drawn people’s attention to where there food comes from, what has been added to it, and how it affects not only one’s body but environment as well. Many consumers now seek locally grown produce, sustainably produced food, certified organic food, or food from small or mid-size producers (Hardesty). A report compiled for the US Department of Agriculture found that the majority of farms that sell directly to consumers are small farms. Large farms are often located in rural areas where the price of land is less. Direct sales to consumers require proximity to large populations (Johnson, Aussenberg & Cohen). The strongest local food markets exist in the northeast and on the west coast. Many small farms in the area are close enough to large metropolitan populations and can earn enough from direct sales. The term “locally grown” has no official definition though, and conscientious consumers must remain alert. The food miles on some products advertised as locally grown may still exceed a consumer’s wishes.

Contributing to the locally grown movement is the dramatic growth in CSA’s, or community supported agriculture, farms. There were just two CSA farms in the United States in 1986. By 2007, 12,549 US farms reported sales through community supported agriculture involvement. They were started reconnect consumers with food production. There is an understanding between the producers and participants described by Hinrichs & Lyson as “a new kind of civic-minded economic contract.” In many cases, this means that those who buy a share in the CSA expect the farm to provide an assortment of produce at regular intervals throughout the years. Other CSA’s require participants to lend a hand with cultivating or other farm operation tasks in order to collect their portion, and still others nearly evenly distribute the farm labor among the participants. On these CSA’s, a significant variety of produce is grown. Contrary to large commercial farms that have dozens of acres for one type of fruit or vegetable, a CSA is likely to grow 40 kinds of fruits and vegetables on fewer than 40 acres. The profit per variety is therefore significantly lower on a CSA than a specialized commercial farm, which contributes to why most new farm machinery today is grossly inappropriate for use on a small farm.

Farmers markets have experienced a similar growth pattern in recent years. While these markets have always existed in the United States, providing small farms with the opportunity to
sell directly to consumers and giving conscientious buyers access to fresh food, there was a nearly a 250% increase in the number of farmers markets between from 1994 and 2006 (Hardesty).

Restaurants, supermarkets and other food distributors are also responding to the emphasis being placed on locally sourced foods. It is common in restaurants today to see

Many farms today are operating as more than just tracts of land where food is produced and then sent off for sale. A variety of disciplines and backgrounds come together to contribute to the success of farms today. On-farm, valued-added processing can increase a farm’s income, but dairy and meat farms are more likely to engage in these activities than fruit or vegetable growers. One common entrepreneurial activity is making an effort to be part of the agritourism industry. Farms and CSA’s host community events like annual harvest festivals to attract customers. Family farm days are commonplace on CSA to educate participants about farm operations and allow people of all ages to interact with the land that produces their food. Seasonal displays decorate a field to entertain children and turn a local farm into a community landmark and a destination for tourists. The principle grower and owner of the farm pictured in Figure 1-8 said he does not like the displays littering his farmland, but he will not interfere with the marketing and creative team that is employed by the farm (Wilson).

Figure 1-8: A farm in Massachusetts decorates their fields with objects like an old VW bug perched on a stand several feet in the air and the UFO with aliens pictured above in an effort to make the farm and destination for local families and tourists. The display is even dressed up with a jack-o-lanterns and a trick-or-treat bag for the Halloween Season.
Additionally farm stands located either on the farm or nearby sell produce directly from the farm but also often sell products from other small-scale producers. For example, locally produced soaps, honey and wax products, specialty cheeses, and preserves are examples of items often found at farm stands but not produced by the farm itself. Other vendors are often provided space to sell their products at the stand, like an orchard getting space to sell cider in the fall or a local craftsman displaying their home goods.

1.2.2 A Changing Demographic

In conjunction with changing public and commercial interest in locally grown food, there is a trend of younger and higher educated farmers getting involved in farm operation. A profession that was historically filled by individuals who inherited farms through their family is now seeing many individuals previously unaffiliated with agriculture attracted to the industry. According to the USDA Local Food Systems report in May 2010, the average direct-to-consumer farmer had several years less experience than other farmers. Forty percent of these direct-to-consumer farm operators fell into the category of beginning farmer—indicating less than ten years of operating experience—and sixty percent fell into the category of socially disadvantaged—a term that the USDA defines based on racial or ethnic identity and gender.

One factor contributing to the engagement of a younger and socio-economically diverse population in farming is the farm-based education programs that have gained momentum in recent years. These programs operate like a trade school to equip beginning farmers with the skills necessary to operate a farm. Participating student farmers may attend a few workshops to develop specific skills, or live, work, and learn on at one farm for years. Other education programs host school-aged children for educational and entertaining camps and activities. Within the state of Massachusetts alone, there are forty-eight farms involved in the Farm-Based Education Network.

A comprehensive view of today’s young farmer is not easily compiled. Some farms are operated by a group of hobby farmers. These individuals do not work on the farm full-time. They may commute to the farm rather than live in close proximity. They often have other part or full-time employment in a variety of professional disciplines. The Internet is littered with blogs kept and frequently updated by farmers documenting their work. Hundreds of homemade videos of new equipment or cultivation, harvesting and maintenance how-to’s have been uploaded to YouTube by farmers from around the world. Online forums are used to share tips and tricks or pose questions to other farmers. Printed catalogues from seed and equipment suppliers are being rapidly replaced by websites that enable online ordering. The trend of new farmers being more connected to technology and exchanging information through such public modes could profoundly influence the rate of change within the industry. Consumers in the agricultural machinery industry may soon defy the conservative nature that has characterized them for centuries. Producers within the industry would be free to innovate at an increased rate, and food production practices could undergo a greater rate of change than at present.
1.3 Salad Green Cultivation and Harvesting

The term salad green encompasses many varieties including arugula, mizuna, tat soi greens, frisee, oakleaf, red chard, mustard greens and some lettuces (Figure 1-9). In the US, spinach is the foremost of these greens with $256.9 million in fresh market sales in 2010, and therefore the focus of most of this project (Boriss & Kreith). Spinach and other salad greens are low-growing leafy vegetables that do well in moist soil and cool temperatures. In the northeast region, these greens are planted in the spring and early fall. They can be harvested after 6 to 12 weeks of growth, depending on the growing conditions and seed variety. California, Texas and Arizona where most of the country's spinach is grown, spinach and other greens are grown throughout the winter months.

![Figure 1-9: Arugula, mustard greens and spinach are examples of salad greens.](image)

Harvesting must be completed before the plants bolt. There is a short window of opportunity for harvesting between maturity and bolting. This makes harvesting particularly challenging on farms where a team of laborers has to be ready to work when the precise time for harvesting arrives. Weather also affects a farmer’s decision about when to harvest. Frosts or unusually hot temperatures can ruin a crop quickly. As such, farmers monitor forecasts near harvest time and may make sudden decisions about when to harvest. Harvesting is best in the early morning while leaves are still turgid. There is no crop selection when harvesting spinach. All leaves are cut which means they usually have to be washed and undergo quality control measures. After washing, they are usually packaged in some manner and then transported. The crisper the leaves are at the time they are harvest, the better they hold up from the field to the consumer. As the day progresses, particularly if it is a warm day, greens lose moisture and are in a flimsier state. This causes them to wilt faster and the greens may not sell.

By 1969, mechanical harvesting of spinach was highly developed and recognized as the only reasonable option for spinach growing operations. The innovations that greens growers needed were not in the area of harvesting methods but in engineering better varieties of spinach and...
mechanical weed removal options (Cargill & Rossmiller). However, these widely accepted harvesting practices were not applicable to small farms back in '69 and still are not today. Highly efficient combine spinach harvesters are available today for a quarter million to one million dollars.

For farms that could not afford a machine like that, there was an option in the $8,000 to $10,000 range. The more expensive of these harvesters is shown in the middle of Figure 1-10. This harvester cut with a band saw blade running across the front. A conveyor moved the greens from the cutting edge and deposited them in bins at the rear. The machine was designed for densely packed baby or mature spinach leaves. A small farm’s annual revenue from spinach and other salad greens is not likely to reach or exceed $10,000 so investing such a sum in harvesting equipment, even if it works remarkably well, is not practical for small farms.

On small farms today, spinach is harvested with scissors or serrated knives. These knives are typically 6-8 inches in length and specifically designed for cutting greens. It is physically demanding to crouch in the dirt along the spinach bed. It is also time consuming – a team of five could be expected to harvest one forty-yard row of spinach in an hour. One supplier has integrated two handles and a collection canvas onto a serrated blade and sells the harvester for more than $200 dollars (Figure 1-10). The operator is still required to bend forward and the supplier warns that some skill, practice and exertion are required for optimal operation.

**Figure 1-10:** Salad green harvesting equipment is shown above on a pricing scale. There is a significant gap between a few hundred dollars and many thousands of dollars that Harvester Version 1.0 would fill.
Only densely packed spinach beds can be harvested with this device because the greens would simple bend out of the way of this slow moving blade when nothing is in place to brace the stems. A slightly modified version of this harvester is shown in below in Figure 1-11. This model addresses the problem of sparse growth with a spinning brush that should push the leaves over the blade to be cut and then fling them into the collection canvas. Selling for a few hundred more than the previous model, this machine requires the farmer to provide the cordless drill that powers the reciprocating blade and the collection brush.

Figure 1-11: This handheld harvester developed by Johnny’s Selected Seeds uses a cordless drill to move a serrated blade and spin a brush that throws the spinach back into the collection canvas once they are cut. The machine costs about $500, without the drill (johnnyseeds.com).

Between the hand-held harvesters going for a few hundred dollars and the large harvesting combine sold for several thousand, there is no compelling option for farmers. The harvesters presented in this paper were designed to fill this gap and give farmers an effective and easily operated machine that cut and collected spinach and other salad greens. The targeted price was $1000, but the first harvesters would have been sold for about $1500.
2. Harvester Version 0.0

1.2 Background

As part of MIT's course 2.009 Product Engineering Processes in the Department of Mechanical Engineering, a team of 18 seniors from the department developed a prototype of a mechanical salad greens harvester. Cooperation with three small farms in Massachusetts influenced the team's design decisions. One farm grew baby spinach on raised beds, as shown in Figure X.x. The beds were approximately 50 yards in length, 40 inches across and raised six inches above the trough height. The distance between the tractor wheels determined the bed width. Spinach grew densely on this farm and there was no produce selection. Efficient harvesting methods approximate mowing the baby spinach then collecting it for washing and packaging. The bed surface was level and the plants were not cultivated for multiple harvests. A single 40-inch blade that could cut at ground level and move quickly over the bed with a collection system following was optimal for this farm. Attaching a harvester to one of the farm's tractors was also an option.

A second farm the team worked with and designed for grew mature greens in discrete rows. These rows were space nine inches apart with three rows per bed. The beds were slightly raised but crowned dramatically. Center to center distance between the beds was determined by the tractor wheels, and matched that of the first farm. The same plants were harvested multiple times throughout a season, but only the mature leaves were selected at each harvest. As a result, this farm had very precise cutting requirements, but the yield from each harvest did not require an elaborate collection system. A rigid 40-inch blade would not provide the cut quality needed by this farm. Rather, a cutting surface that only spanned one row and could adjust to the uneven bed was preferable.
Figure 2-1: On the left, baby spinach grows densely across raised beds. The beds on the right are crowned and the spinach is grown to maturity in discrete rows.

The third farm the student team coordinated with grew spinach in discrete rows across 96-inch beds. These beds were at ground level, and the bed geometry was not conducive to running a tractor over it. Consequently, a chassis designed to run along the troughs at the first two farms would trample greens at the third. Meeting each geometric constraint was not feasible, so the team decided on specific operating conditions and made design decisions accordingly. The blade could ride between two and eight inches above the wheel bottom height. This allowed for cutting of fields without a raised bed up to beds raised six inches.

2.2 Frame

The harvester needed a robust frame that could handle uneven terrain, support all the components but remain maneuverable. The frame needed a platform for the functional units and housing for the wheels. The initial frame was constructed from square steel tubing. This first frame - at ten feet long and six feet in width - proved to be larger, heavier and stronger than optimal. The second frame had a footprint of less than thirty-six square feet and used thinner circular steel tubing, as shown in Figure 2-2. Some square tubing was welded in place for easy attachment of the blowers, which were bolted into place Caster wheels on the front allowed for easy turning by the operator, who pushed and guided using a handle bar at the front end of the harvester (Figure 2-2). Two operators could push simultaneously from either side of the bed, but the harvester was intended to be manageable for just one operator. Handlebar tape was applied to operator’s bar and the steel tubing was capped on either end of the bar in order to give the
frame a more pleasant user interface. By positioning the operator at the front of the machine, it allowed them to walk in the trough and maintain a direct line of sight to the cutting blade. Large wheels were mounted back of the harvester, providing the ability to traverse uneven or soft ground with ease.

![Figure 2-2: Each steel component of the harvester is modeled above. The majority of the frame is circular tubing. Sheet metal provides a base for the collection bins as well as a barrier between the fumes from the gasoline powered generator and freshly cut greens. Square tubing at the back provides simpler mounting opportunities for the rear wheels and a location for the vacuums to be bolted on. Small plates are welded onto the front for the caster wheel attachment. The tube across the top front is the operator’s handlebar, and the parallel bars along the bottom front provide the attachment guides for the floating chassis.](image)

While the frame had coarse adjustment capabilities for rough terrain, fine adjustment of the cutting blade was required in order to obtain the desired cut quality for salad greens. A chassis holding the cutting components had an additional degree of freedom from the frame. This allowed the blade to move up and down according to variations across the surface of the bed. The width of this chassis was less than that of any standard bed, allowing even greater control along the portion of the bed being cut. However, a thinner cut length meant attaching multiple cutting units to the frame or doing multiple passes over the same bed. For this reason,
the chassis needed the freedom to attach across the width of the frame. Parallel bars along the front of the flame allowed the blade unit to be attached at any point across the frame width.

2.3 Carriage and Cutting Mechanism

A pair of slotted sliders on either side of the cutting carriage kept the apparatus attached to the harvester’s main frame. These sliders were designed to allow travel up and down according to variations in the bed surface. A pin extending from the carriage kept it attached to the sliders. Flanged plastic bushings kept the pin from rubbing directly against the aluminum slot and provided a low friction interface to encourage the carriage’s bed-following height adjustments. Constant force torsion springs were pinned between each pair of slotted sliders and fixed to the carriage attachment pin. This provided a constant upward force on the carriage intended to offset some of the carriage’s considerable weight and prevent the blade front from pitching downward into soft and uneven soil. The slider, pin, and spring assembly are shown in Figure 2-3. The sliders were bolted onto parallel steel tubes on the frame. This fixed the sliders rigidly on the frame when the bolts were tightened but left the operator the freedom to loosen the bolts and move the whole carriage to any position across the harvester frame width. All other structural parts of the harvester were made from steel because it could be welded. Nothing needed to be welded onto the sliders though. Aluminum was the preferred material because it more than met the strength requirements for the part yet was less expensive and lighter than steel.

The motor that powered the cutting mechanism was located on the cutting carriage so that it could remain a consistently distance from the blades. The motor was mounted in the center of the back end of the carriage with the output shaft facing downward. This upside down mounting configuration was advantageous because it minimized the height of the blade drive shaft, and allowed the collection plenum to go underneath rather than deforming around the motor. The adverse effects of mounting the motor upside down though was the carriage’s increased center of gravity and the added weight of the steel mounting components required to support such a mount. The motor casement had a rigid base attached to it and was design to be bolted down in four places. A steel plate with holes drilled into it was welded to the motor mount frame, and the motor was Part of the motor mount was 3/4-inch steel tubing. Most of the structural parts of the carriage were built from this tubing and welded together.

To offset some of the weight of the carriage, springs were attached to the back of the carriage assembly and then chained to the harvester’s frame. By changing the length of the chain, the operator could make course adjustments of the carriage height relative to the frame. With this control and the sliders automatically adjusting height on the front end, the harvester could cut at a height anywhere between 2 and 8 inches from the rigid frame wheel bottoms.
The slotted sliders, modeled on the left and pictured on the right, attached the cutting carriage to the frame and allowed the carriage travel up and down according to the terrain of the greens bed.

To distribute the carriage weight across a broad base and keep the blade from digging into the ground, an abs plastic skid plate was installed across the entire bottom of the carriage. This plate was upturned slightly at the front end to encourage going over bumps rather than plunging into them. This skid plate was attached by bolting it into the aluminum base plate upon which the blades and collection plenum were fixed.

The harvester’s cutting mechanism was a set of reciprocation hedge trimmer blades approximately 20-inches in length. The geometric specifications that these blades met were achieved by repurposing 40-inch trimmer blades. The process of the modifying these blades was more complex than originally intended. Shortening and removing teeth at the end attached to the drive mechanism ended up work hardening part of the blade. When it came time to drill and tap that same end, the blades could not take a thread, and broke multiple taps in the attempt the thread. The blade tip had to be annealed and tapped while the steel was still cooling. The work required to prepare one set of blades was not an efficient process and would prove very costly if a whole run of the machines had been produced.
A ½ horsepower NEMA motor, frame number 56 base mounted AC motor was used selected to power the cutting mechanism. This motor had a totally enclosed fan-cooled enclosure, which was preferable to prevent damage during use outdoors, around dirt and high humidity. The motor had automatic overload protection and ran at a speed of 1,725 rpm, which means the blades were cutting at 3,450 rpm. There was a pulley attached to the 5/8-inch motor shaft. This pulley was connected by a v-belt to the blade actuation shaft. The blade shaft had a ½-inch diameter, but the pulleys had the same outer diameter, which kept a 1:1 ratio between the motor and cutting shaft rpm's. The benefit of using a pulley system was that it allowed the motor to be mounted at the rear of the carriage where its significant weight was located most advantageously while the blades were mounted on the front edge.

The distance each blade had to travel for one full cut was half the distance between blade teeth. With upper and lower moving in opposite directions, this ensured that with each stroke, the teeth aligned perfectly to allow spinach into the entire tooth gap area, and then closed, shearing all stems in the gap. The tooth-to-tooth spacing was 1.7-inches. These blades were attached to the carriage through four slots that were put in by the blade manufacturer. A bolt went through each slot with a bronze sleeve bearing to minimize friction and was secured with a lock nut. The sleeve bearings wore down quickly though, and the machine operator would have had to replace them after each use.

The second pulley connected to a ½ inch keyed shaft. This shaft was located on the front edge of the cutting carriage and attached by two pillow block bearings (Figure 2-4). At the base of the shaft, a Scottish Yoke design translated the rotation of the shaft to reciprocation of the hedge trimmer blades. The Yoke was comprised of upper and lower plates intended to shield the precisely fit components from some of the dirt and debris in close proximity as well as keep lateral pressure on the eccentric components and blade cams to ensure the only motion of the cams and blades was in the intended direction for cutting. To achieve the full cutting motion described earlier, the eccentric cam pieces of the yoke extended 0.85 inches asymmetrically. Two of these pieces, mounted opposite one another in the Yoke assembly were made from copper. They were bolted on to the shaft and pinned in place. Copper foil was used to create a gap three thousandths of an inch wide. The copper shims reduced some of the friction between the moving cam components.
Figure 2-4: SolidWorks rendering of the Scottish yoke mechanism with blades attached.
2.4 Collection

Once greens were cut, they needed to be transported into bins for easy collection and transport. The harvester’s collection system used two industrial vacuums and a series of airways to move leaves from the blade-front back in the collection bins. The first part of this system was a set of symmetric collection plenums that spanned the length of the blades (Figure 2-5). The tops of these plenums were made from thermoforming plastic. The rectangular cross-sectional area of 40 square inches at the front of the plenum tapered to a 16 square inch cross section directly adjacent the end of the transport tube.

The bottom of each plenum was consisted of two layers of plastic with a gap between into which air from the vacuum back flow was pumped. The upper layer was covered with holes through which the air could escape. The goal was to prevent cut greens from getting caught in the plenum and never making it through the collection system by pushing them upwards while the airflow through the plenum pulled them back.

Flexible, clear plastic tubing was connected to the back to the plenums. Though the ribbed and bent nature of this tube meant more losses in the airflow, the material had to be
flexible in order to accommodate the movement of the cutting carriage. This tubing ran up to the special top of the collection bucket whose location was fixed on the frame, unlike the plenums on the carriage (Figure 2-6). This specific top was connected to two tubes. The first, as described, carried air and cut greens from the cutting carriage up to the bucket. The greens dropped to the bottom of the bucket while the air circulated and was pulled through the second tube on the bucket top. This second tube ran to the vacuums, which were mounted on either side of the generator. These tubes crossed over one another. While this added to the overall length of the tubing, the airflow losses incurred by a sharp turn were less than the losses of a longer but straighter section.

The backflow from the vacuums was piped along the side of the machine to the collection manifold at the very front. This manifold had nine smaller pipes running off that directed airflow toward the plenums. The purpose of this air was to prevent freshly cut greens from falling forward, back into the blades, and never reaching the collection buckets. The framework for the manifold was cantilevered off the cutting carriage and over the parallel bars that the sliders were mounted on.

Figure 2-6: The entire machine is shown above with all collection components visible. The clear tubing is flexible, while the dark gray components are rigidly attached to the frame.
2.5 Power

Figure 2-7: An operator grips the harvester’s handlebars with thumb on the kill switch, ready to depress it and enable the flow of electric current to the cutting and collection systems.
As discussed in the farm equipment power section, there were many options for the team to consider as they planned to power the harvester. The following outlines the thought that went into each option and why an electric generator was finally selected. Before these considerations are discussed though, it is important to layout exactly what components needed a power source. The cutting mechanism required some power in order to move blade at a high speed, but little torque was required to cut salad greens. In fact, the power requirement was only about a quarter of the 0.87 hp that the engine of the hedge trimmer for which the blades were designed supplied. The motor that was selected to drive these blades output one horsepower but required 0.5 kW. On the collection side of things, the vacuums required considerably more power than the cutting motor, and there were two of them. In total, 3 kW would be needed for collection. The team considered incorporating drive assist to one of the rear wheels. This feature would make the harvester easier to operate by just one person. As designed, there was space on either side for an operator to stand and push, but force required to move the harvester was manageable for just one person. Keeping the harvester going straight was the greater challenge when only one person pushed. By installing a motor to one wheel that matched the effort of the operator pushing from the other side, the operator would have a simpler task. Because the machine was operable without this feature, it was not prioritized and ultimately not implemented. As the power source decision was made though, the team tried to budget for an extra kW that could be diverted for a power assist wheel.

The team initially planned to use a rechargeable battery but ruled the option out after more thought about storage, charging, and the barrier to adoption in farming environments. The power required to run blowers and cutting motors over the course of a harvest meant the battery would have to be several hundred pounds and incredibly expensive. In addition, the farm would have to keep this battery charged constantly during harvest time, because – as the team learned at the Wilson Farm – sometimes the decision to harvest was made last minute because of weather forecasts. Finally, should the battery run out during a harvest, it is unreasonable to expect a farm to keep two large, expensive batteries on hand just for this machine and have the second waiting to replace. The advantage of battery power is the ability to electronically control each component powered through the use of simple controls. Also, it is a "clean" energy option for use in the field.

PTO was an option never really explored because no one on the team was familiar with the interface and it seemed a leap too far to learn the system and design for it by the time the idea was introduced. There were no concerns about the anticipated performance of this option; it just seemed too hard. The advantage of using PTO is that almost all small farms in the US today
own and regularly use a tractor so there would be a low barrier to adoption. The fuel requirements would be not different from what farms were already accustomed to because it’s just fueling the operation of the tractor.

Gasoline was considered for it’s significant energy efficiency advantage over electric options. However, there was the concern of needing to install clutches and make sure there was a way to throttle each individual component. Otherwise, starting the engine (or engines) would supply power at a constant rate to all components. There would likely be situations where the collection system needed to run while cutting was disabled. In fact, anytime the cutting could be disabled was desirable because it lowered the risk of an accident as well as potential damage to the blades from running into rocks or other debris. Finally, team members were concerned about the emissions from the engine in proximity to fresh produce and potential drops of oil or gasoline onto the fields.

The selected power source was a gasoline-powered generator. Gasoline, with its advantage of being the fuel farmers already kept on hand for equipment like tractors, leaf blowers, mowers and more, was a preferable option for the harvesting machine. Also, the controls capabilities afforded by virtue of the fact that each subsystem would run off the electrical output of the generator were compelling. Finally, the generator did not to remain on the harvester while the machine was not in use. Instead, the generator could be used for a variety of other tasks around the farm between harvests and during the off-season. The platform on which the generator was mounted and attached was not designed for any one design of generator. Rather, it was designed to hold any number of makes and models that met the power requirement needs. The specific generator purchased for the prototype was a 3.5 kW Honda generator. Nearly all 3500 of those available Watts were required for normal operation of the harvester. Cutting used a 1/3 hp motor that took about 500 W to operate. The collection system included two vacuums that each drew 1.5 kW. There are safety concerns with the use of a generator though. If the generator was permitted to run in an enclosed area, CO emissions from the burned gasoline exhaust could reach a deadly concentration in the air.

A circuit box was mounted on the back wall on the other side of the generator. It was not easily accessible, by design. The only time the operator would need to access the box was if a piece of equipment needed to be replaced, or something was broken. The controls that the operator would use regularly were mounted in a small box in the center of the operator’s handle bar (Figure 2-8). This made it accessible to an operator from either side. First, the generator had to be pull started from the back of the machine. Once it was going, the vacuums and cutting motor could be started from the front of the machine with the toggle switches on the control bar.
However, none of these components would work unless the operator’s kill switch was depressed (Figure 2-7). This safety measure meant that the blades would only run if an operator were standing at the head of the machine, with a direct line of sight to what was being cut. Additionally, the kill switch feature meant that if anything happened to the operator that caused them to remove their hands from the handlebar, power to the cutting motor would immediately cease.

Figure 2-8: Toggles on operator’s handlebar control power to the cutting motor and collection vacuums.
2.6 Performance

Figure 2-9: The harvester stands onstage before an audience during the 2.009 final presentations in December 2013. One team member addresses the audience while a second waits to operate the harvester. Rather than run the generator indoors, the components that needed electric power were plugged into AC sources.

The harvester ran for approximately ten seconds during the 2.009 final presentations before an audience of about 1500 people (Figure 2-9). During those ten seconds, the harvester moved forward three feet. The spinach that had grown within those three feet was cut and engaged with the collection system. Some leaves traveled through the collection manifold and all the way to the collection bin. A few were trapped in different parts of the collection system along the way, but for the collection system in general performed as intended. Cutting, likewise, completed the job. When the harvester was moved back to show the audience what kind of cut quality it provided, there was little to see but a bald patch of soil. The reason the run only lasted about ten seconds remains somewhat unclear. The operator mentioned that the perceived resistance to forward motion had increased to an alarming level by the end of the run, when she removed her hand from the safety start button, cutting power to the rest of the machine. She hoped to avoid overloading and burning out the motor before an audience as the team had
experience with a previous model when its blade sunk about 3 inches into the soil. The motor did not burn out, and there are competing theories concerning where the heightened resistance came from. One idea is that the cutting carriage had pitched forward and the blade was digging into the soil. The second theory is that the harvester was not properly situated across the raised bed. For the purpose of demonstration on stage, the raised bed was garden box with a wooden frame. Some team members assert that as the machine moved forward, the rear wheel mount ran into the wood bed frame and dramatically increased the operator’s sense of resistance to forward motion. Either way, a great deal stood to be learned from repeated tests with Version 0.0 of the harvester; however, its inaugural run marked the end of the course. The generator and some other components were quickly salvaged and the prototype was never again fully assembled and tested.
3. Harvester Version 1.0

3.1 Background

In the spring semester of 2013, one team member from the team that built the first harvester prototype continued work on the concept and design a second version. The historical context into which new agricultural machinery is introduced was studied with greater depth than the previous semester, and design decisions were influenced much more by industry standards. All the major systems that were included in the first version remained in the redesign, but significant changes were made to each. The following sections outline each of these systems and the reasoning behind the design.

3.2 Frame

The harvester’s frame was designed from 3/8-inch steel bent and welded into place. This steel was powder coated black as a weatherization treatment. The front of the harvester is a three-point hitch system. This is a standard hitch configuration that comes on most tractors sold today. With one rod end coming off the back of the tractor three to four feet above the ground and two rod ends coming off the tractor about two feet below the ground, an implement can be cantilevered from the tractor. The lower hitch bars actually consist of two rod ends on either side of bar. The back rod ends get clipped to pins that are rigidly attached to the tractor. Chains or additional rod end and shaft combinations support the lower hitch bars and can be adjusted to raise or lower the attachment point. On one John Deere model, shortening or lengthening an attached chain can adjust the top attachment rod height, and the lower bars use a combination of chains and bars to adjust the lower bars (Figure 3-1). Not all hitches are the same though. There is a system of categorizing and standardizing the different hitch models across the industry. A tractor’s hitch falls into one of five categories based on the engine power. The harvester was designed for Category 2 tractors and hitches. The power range for Category 2 is from 40hp to 100hp. According an owner’s manual for such a Category 2 tractor build by John Deere,
Figure 3-1: The three-point hitch on a John Deere tractor is shown with a removable drawbar connected across the bottom.
	his means the upper link pin should have a 1-inch diameter while the lower link pins should be 1.1-inches in diameter. The pins are held in place with a cotter pin. There is 32.48-inch span between lower hitch connection rods, and 24.02-inch distance between the top and lower connections. While the small farms that are the intended customers for the harvester are likely to own a Category 2 tractor, the difference between categories 2 and 3 is slight, and very little about the harvester would have to be changed to accommodate. The necessary changes include increasing the upper pin diameter by ¼ inch and the lower pins by 0.34 inches. The final difference is the distance between the lower hitch points. The additional 5.49 inches in the Category 3 standard could be accommodated by pinning the lower points on the outside of the hitch rather than the inside as designed now.
The collection apparatus would all be cantilevered off the hitch (Figure 3-2). There are rollers intended to rotate as the machine moves and drive the collection conveyor.
These rollers are not specifically load bearing though, and will only carry enough of the mechanisms weight to have traction in the soil. The cutting carriage will also be connected to the harvester via a four bar mechanism on either side of the carriage. Two sets of threaded connection rods with pin diameter of 5/8-inch attached to a shaft with left-hand threads on one end and right-hand threads on the other form one of the parallels in the linkage. By twisting the shaft, the farmer can adjust the carriage height according to the height of the beds that will be harvested.
3.3 PTO Specifications

Power take-off shaft manufacturers design shafts specifically for one piece of equipment. Discussion with a PTO manufacturer out of Minnesota, Weasler Engineering led to the specifications for the harvester’s shaft. A Weasler 35 series needle bearing style shaft was selected. This shaft is rated for up to 51hp. The John Deere category 2 tractors used for design output a maximum of 37hp to the PTO, and less than one is required to power the cutting mechanism. The available power seems grossly inappropriate for the harvester, but the operator can throttle the PTO output, and the goal is to attach the machine to a power source already in use on the farm. The shaft is designed for rotation at 540 rpm and attachment to the industry standard splined output. This splined shaft, according to SAE Standard J1170, has six teeth cut into a shaft of diameter of 1.375 inches. A circumferential groove 1 inch down the shaft serves as the hub attachment point for the female ends on the PTO shaft. The extended length of the shaft comes to about 3.5 feet. Movement of the cutting carriage causes a change in the operating angle of the shaft. Angles of up to 32 degrees are manageable with the universal joints of the shaft, but the greatest operating angle required by the harvester is less than 15 degrees. A standard black plastic PTO shield covers the shaft both to keep some debris off and protect from operator injury.

3.4 Carriage and Cutting Mechanism

The harvester’s cutting carriage was designed as the connection between the PTO shaft and the cutting mechanism. ¾-inch square tubing provided the carriage’s framework, and aluminum sheet metal covered the bottom. Two or three 5-inch skids were bolted into place at the operator’s discretion, according to the bed geometry. On a bed with discrete rows of greens intended for multiple harvests, the skids could run between rows. When the bed would be tilled and reseeded after harvesting, the skids could be mounted to run anywhere across the bed. The male attachment point was part of a Weasler beveled gearbox that was mounted to the carriage. The bevels were at a 90-degree angle to one another with a 3:1 ratio. The output from the gearbox was vertical, facing downward. A sprocket attached to this output shaft was connected
via chain drive to another sprocket atop the blade drive shaft. The sprockets, chain and shaft were enclosed on three sides by a cast iron shield for safety.

At the base of the blade drive shaft, a Scottish yoke mechanism similar to the one designed for Version 0.0 was in place to move one reciprocating serrated blade. The lower blade was fixed to the carriage rather than reciprocating. With the shaft rotating at 1,620rpm, the blades made 3,240 cuts per minute. Because the tooth-to-tooth distance on the serrated blade was much shorter than on the hedge trimmer blades, the reciprocating blade did not have to travel as far for each cut. The designed stroke length was 0.5 inches. These blades would require some maintenance between uses. A round diamond file could be used to sharpen them.

Figure 3-3: Rendering of the cutting carriage solid model. The gearbox sits on top, and the belt and blade shaft cover extends the lefts. Pins extend on either side where the threaded rod ends connect.
3.5 Collection

The collection system of Version 1.0 was greatly simplified from the previous version. Because the machine is pulled by a tractor rather than pushed by a human, it could travel much faster down the row. Concerns about the greens falling forward rather than tumbling back toward the collection system were alleviated. The vacuum and blower system was completely eliminated. Rather, a conveyor belt kept close to the cutting edge moves greens from the front up to collection bins at the rear of the machine. This conveyor is ground driven from rollers on the ground behind the belt. The belt axle it attached to the conveyor axle via pulley and v-belt (Figure 3-4). A 1:1 ratio between ground speed and belt speed is maintained.

Figure 3-4: All the steel hardware components of the Harvester Version 1.0 are shown above in the render. In addition to the steel components, the conveyor is displayed.
4. Summary and Conclusion

Endless design alternatives exist for every component of the harvester. The cutting mechanism could be switched to a band saw blade rather than reciprocating. Bed following capabilities could be refined beyond just the four bar mechanism by adding a degree of freedom at points across the cut length. In the reciprocating model, the blade could be divided into independent sets on either half of the carriage. By allowing these sets to rotate about the outermost points, the blades could rise upward in the center of the bed to accommodate crowning, and foreign obstacles that force the blade up would only disrupt the cut height along half the bed. Setting skis at various points along the blade could add fine adjustment freedom on the band saw model (Figure 4-1). As the skis go over uneven soil, the bottom of the band saw blade would not remain horizontal but adjust with the variations of the bed in order to keep as close to a uniform cut length as possible.

![Figure 4-1: Annotated sketch of a collection carriage design with a band saw cutting mechanism and fine adjustment across the width of the bed provided by three skis.](image)

On the collection side of things inertia may, in fact, not be sufficient to get the leaves back from the cutting edge to the conveyor belt. To fix this and cut losses by ensuring that the leaves make it all the way into the collection bin consistently, an additional component may need to be added to the machine. Combine rice harvesters incorporate rotating combs that push the grains toward the blade and then beyond into the collection bins (Figure 4-2). Bringing back aspects from the vacuum and blowing system of the previous version may be advantageous. A blower could be attached.
Figure 4-2: Part of a combine rice harvester is sketched above. A set of three combs rotate, pushing the grains over the blade and back into collection bins.

The success of the design choices that comprise Version 1.0 cannot be fully evaluated until the prototype is tested on a few farms. The next step for this project is therefore building a second prototype and undergoing thorough tests with a variety of field conditions. The prototype should also be used to gather feedback from farmers. Successful development of an inexpensive salad greens harvester would help small produce farms in one way, but it is only a step toward the overall transition inventors, entrepreneurs and manufacturers need to make to equip small farms with the technology that is already in use on large farms.
BIBLIOGRAPHY


