FINAL REPORT

Rob Rock and Andy Crawford

Building and Evaluating a Pedal Powered Prone Workstation and Row Crop Cultivation Tool
SARE FNE-07-603

Thanks

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Goals

The goal of our project was to assess the viability of using human/bicycle powered vehicles to accomplish a number of tasks found in a vegetable row-cropping system. During the 2007 and 2008 growing seasons, with the use of personal and SARE funds, we designed, built, and tested what we have descriptively called a “two person pedal powered prone workstation”. Sets of trials were conducted for the tasks of hand weeding and transplanting. The vehicle's suitability for mechanical cultivation with one and two riders was also tested, and some strategies for using the vehicle for cultivation were developed.

For our fourteen hand-weeding trials, we saw an average 28% decrease in the time spent per bedfoot hand-weeding a 3 row closely planted crop. This was equivalent to an average time savings of 19 minutes and 42 seconds +/- 1 second on a 400 foot bed.

The nine transplanting trials resulted in an average 9.22% +/- 0.16% decrease in total planting time with the prone workstation. The number of samples in the transplanting trial is not significant enough to verify that this margin is statistically robust, but is consistent enough to give users an indication of what can be expected. Over a 400 foot bed the actual difference in time amounts to 7 min. 28.8 seconds +/- 7.8 seconds.

During cultivation experiments, we found that any task requiring more than approximately 0.45 kN of draft force was physically unsustainable by two healthy and fit adults. A drag style spike tooth harrow was the most aggressive cultivation tool successfully pulled. The estimated total human muscle power output to achieve this is on the order of 500 +/- 100 Watts, or 0.67 +/- 0.13 HP, which puts a reasonable upper limit on the cultivation tasks that can be attempted with two riders on this vehicle and other similar human powered vehicles. Human power output below that value is sufficient to lightly cultivate the un-cropped portions of a 48 inch wide bed with tools intended for hand and wheelhoe use.

Farm Profile

The project was a collaboration between Andrew Crawford and Rob Rock, two organic vegetable farmers working for Arethusa Collective Farm located on the Intervale in Burlington, Vermont. The farm cultivates roughly 14 acres, growing a variety of market garden crops for the Saturday Farmer’s Market in Burlington, but realizes the greater part of its revenue from the wholesale of mesclun mix, carrots, eggplants, and hoop house tomatoes to area natural food stores, co-ops, restaurants, and grocers. The predominant soils on the farm consist of sandy loam on river bottom land, and are comparatively light and easy to work, with no hills in the fields present.

Participants

Our technical advisor, Dr. Daniel Baker, UVM Assistant Professor of Community Development and Applied Economics, offered us guidance in the planning and the development of a timeline for the term of the grant process, as well as guidelines for data collection procedures.

Project Activities

1.) Vehicle Design and Design Assessment

The prone workstation is a quadracycle, or four wheeled pedal powered vehicle. The design positions two people side-by-side, who would ordinarily be crawling on their hands and knees down a bed of crops. The vehicle roughly resembles a massage table with forehead and chin rests, so that the riders are looking directly at the ground ahead of them. Each rider has their feet on a set of bicycle pedals, and turns a crank which transmits power to a rear wheel, one for each rider. In this position, all of the crop rows in the bed are within reach, the head and back are rested in a comfortable position, and both hands are free to work.

We did have a little help (and inspiration) from a book written by a very funny and eccentric bike builder calling himself the "Atomic Zombie". Some of the basic concepts for our machine's transmission were roughly adapted from one of his designs, but perhaps more importantly we were really encouraged because he builds out of scrap metal and junked bikes in a very primitive welding shop. Some of his tutorials may be found at http://www.atomiczombie.com. We used only the most basic metal working tools, and the skills required for the project could be easily obtained from a night class at an area vocational school, with the help of a little bit of practice. A similar vehicle could be built using a moderate to large sized drill press, an angle grinder, a sturdy vise, a 220V arc (or "stick") welder, as well as a few of the basic hand tools of the metal shop such as a tap and die set and files. We originally had planned to have some parts machined, but due to delays at the machine shop, we eventually went ahead and made our own parts from existing used bicycle components.

The design phase was fairly easy compared to the construction. It was probably late in August once it was actually completed and ready for field testing. (Note: When we suggest in the report that the vehicle has been "completed", keep in mind that this word is used rather loosely. Whenever you develop a prototype, it quickly becomes clear that there are always adjustments, revisions, and improvements that can be made, even when the prototype is fully operable. Some of the challenge of developing a prototype is then determining when it no longer requires investment of further resources. The best advice we could give to folks hoping to develop a new tool or a prototype is to start as early as you can, and as much as possible keep the construction phase from dragging out into the growing season. There is a period of time between learning that you have been awarded grant funding and the actual moment when you receive the funds where you may be unable to proceed, but if you have any cash on hand whatsoever it would be wise to accomplish as much as possible.

2.) Frame and Steering

The frame itself is made from 0.065" thickness 1.5" square mild steel tubing, and 3 standard bicycle head tubes, headsets, and forks. Two of these sets allow the front forks/kingpins to rotate for steering. The other one allows the entire front end of the vehicle to pivot in a vertical plane around a forward pointing axis. This keeps all four wheels on the ground in undulating or bumpy terrain. To make this forward facing axis pivot, the fork blades were cut off the third fork and discarded. The top portion of the third fork was then welded to the front of the rear frame. This pivot is quite similar to how modern tractors keep all of their wheels in contact with the ground without suspension. The remainder of the suspension and necessary soil flotation was provided by large, 2.5", 3" or 3.7" pneumatic bicycle tires. The fork head tubes were installed perpendicular to the pivot head tube, on another section of square tubing, but could have used 22-30 degrees of tilt back from the vertical to create a more proper amount of trail for the steering system. To get around this, we flipped the forks backward to move the steering axis to a more stable location, which created a caster action that reduced the need to steer the vehicle when riding it in wheel tracks. The steering system used three modified quill style bicycle stems to form an Ackermann style steering setup. One stem was modified to provide a post that provided a pivot for the central moving parts of the steering system. With that pivot in the center and attached to the headset that held the front end of the vehicle to the rear, we were able to isolate the rotation of the front end in the vertical plane from the work of steering. A rotating plate on the central pivot point took steering input from the steering lever attached to the main frame between the riders and transfered it around the pivot point to two tie rods that connected to the final two stems, each affixed to a fork and responsible for turning one of the front wheels.

While the initial steering setup worked, we began to use it less and less in favor of turning the wheels by simply pushing their rims and tires. To achieve this, we kept the linkage between the central pivot and the two front wheels, and so moving one wheel also moved the other. Because we were moving at a walking speed or slower, the original perceived danger of fingers getting caught in spokes was not a reality. This in turn made the vehicle simpler to steer and more efficient. It took the hand of the steering person that was towards the inside of the vehicle and made it available for a task, while the outer hand was available for steering. Most of the time, with the vehicle in wheel tracks, no steering input was needed for relatively long periods of time.

3.) Transmission

The front part of the transmission is made from two bottom brackets, one for each rider, attached to a clamp which slides along the square tubing and is secured by metric hex cap screws. Standard mountain 110 BCD 175mm bike cranks with a 24 tooth inner chain-ring complete the first stage. The second stage of the transmission consists of a rear 135mm bicycle hub with several widely spaced gears on the freehub body. The first chain goes from the chain-ring to the mid drive hub and is tightened by moving the bottom bracket forward or backward until the chain is tight. A second chain also connects to different cog on the same mid drive freehub body to a bicycle drive-side crank arm. The crank arm was modified by boring a 3/4” hole where the square taper normally resides, and by drilling and tapping a key screw hole that allows you to lock it to a 3/4” shaft with a keyway or hole, and the crank arm where the pedal would normally mount is then cut off. The final stage of the transmission connected the ¾ inch shaft with the final chainring to the rear 26” cart wheel. Two pillow block bearings per side attached the ¾ inch shaft to the frame, and allowed it to spin freely. The internal bearings of the cart wheels were bypassed by bolting a flange we fabricated to the cartwheel hub and then securing it to the 3/4” shaft by a key. The second chain was tightened by moving the rear bicycle hub away from the ¾ inch drive axle and chainring until the chain was tight. Drouputs were made that allowed movement of the mid-drive hub in this direction. This setup provided a wide range of gear ratios to test in different soil conditions. We found that a very good ratio for both weeding and transplanting was to bypass the mid-drive and use a 24 tooth inner ring directly driving the rear 56 tooth chainring. This gave sufficient torque to the rear wheel but also allowed a speed that took good advantage of a prone position. The transmission, both with and without the mid-drive was fixed, meaning that the transmission worked in both forward and reverse and that whenever the wheels were spinning, the pedals moved as well. This required some communication between riders to synchronize pedaling. It also meant that the riders resisting movement of the pedals served as a brake.

Because of the gear reduction on the prototype, when pedaling hard, near maximum amounts of power output, there was a significant force that tended to pull the clamped bottom brackets back toward the other parts of the transmission, and it was more pronounced than that of a normal fixed gear bicycle because the inverse gear reduction produced that much more torque. When the force needed to slide the bottom bracket mount backwards was less than what was needed to spin the wheels forward, we experienced this bottom bracket slip. This slip led to a slackening of the chain, and increased chance of accidental chain derailment. This situation also adds more stress to the chain and shortens its life. We now suggest using slots for the pillow block bearings so that you may adjust the final stage of the drive system and the mid-drive, leaving the bottom bracket welded in place. In addition, using a bolt on chainring guard or rock ring can also help prevent derailment.

We have found it useful to have a fixed gear drivetrain for the simple way in which it provides you a reverse gear. However, the slow speed it travels at is a hindrance. The system could be set up with rear derailer gears mounted on the final drive shaft, front derailer gearing, or an internally geared hub as a mid-drive (using a hub disc brake mount to attach additional gearing). If you are only building a vehicle for one rider, a go-cart differential could also be useful. Recently, other transmission options have also begun to appear, including infinitely variable internal hubs that allow for the very fine control desirable in cultivation operations.

Efficiency of the transmission is paramount, every bit of the power output from a human needs to get to the drive wheel. When by-passing the mid drive, a clean fixed gear bicycle drivetrain can be 97% efficient. Internal hubs are generally 81-92% efficient. Differentials are liable to be more inefficient, but do some really useful work in vehicles that drive two wheels from one input and need to be able to turn sharply.

The drivetrain could also be improved by protecting it from the elements and by choosing much more expensive stainless steel for the shaft and fixtures.

4.) Tires and Wheels

We would suggest tires that are at least 3” wide and wheels of 26” at a pressure of 15-25 psi. The large footprint and diameter of these wheels helps to maintain flotation on the soil. Tires of 2-2.5” tended to sink enough that it made pedaling noticeably more difficult, even in wheel tracks. The best performing tires we tried were the 3.7” Surly Endomorph tires, as their tread more closely resembles that of a tractor tire and they are designed for bicycle riding in loose sand and snow. These tires and their tubes are extremely expensive, so it became clear to us that extra wide bicycle tires like the Kenda Flame meant for “hot rod” bikes are a more economical alternative.

5.) Seat and Ergonomics

The seat started out by looking at designs from other motorized prone devices. The seats for the prone workstation used marine upholstering fabric over open cell sofa pad foam. The frame for the foam was made of plywood and 1.5” by 0.125 thickness angle iron that was bent into a frame which allowed the operator to adjust the seat forwards and backwards, up and down, etc. We drilled holes in this frame and used combinations of pins either above or below the tube that allowed us to realize different seat angles.

We had initially attached a head rest to the seat by bending a piece of EMT in the same fashion as one would find on a massage chair. It seems however that the head rests most comfortably on the chin, and we ended up using the front of the padded seat as a chin rest.

A number of challenges presented themselves to us during the time we spent on this project, but perhaps the most pressing would be the ongoing need to improve the seat or “body rest” on the vehicle so that the operator feels more comfortable both during and after use. A second iteration of the seats could be built, this time enlisting the technical assistance of an ergonomics expert. Because we found that little energy output is necessary to propel the vehicle at very slow hand weeding and transplanting speeds, a second solution may be to eliminate one of the transmissions so that only a single operator need pedal – creating in effect a seat for a passenger who may assume an even more comfortable position.

TRIALS

1.) Hand Weeding Trials

Activities and Results

Relative efficiency measurements of prone weeding was made in a series of 14 time-based trials In each trial (approx. 400' bed), prone or hand weeding was measured in total labor minutes per bedfoot (min./bed-ft.), accomplished through the use of a stopwatch and a measuring wheel to verify each bed's length before the trial. all beds were 56” wide (wheel track centers). The hand weeding for comparative trials occurred on the same date, on an adjacent bed of the same succession of the same crop. Once again total labor minutes per bedfoot (min./bed-ft.) was recorded. This provided control for variations in weather, weed pressure, and soil conditions. Each person on the prone platform participated in both hand weeding and prone trials to control for variations in personal weeding speed. The order of trials within the workday was alternated to make an effort to control for fatigue levels. Subjective comfort levels were ascertained by noting the general feeling of the weeders at the end of each bed. Equal numbers of rows were weeded in crawling and prone positions for each bed. The crop being hand weeded was baby lettuce and should be similar to any other closely seeded 3-row crop. For each trial, beds had identical numbers of rows and all rows were completed in each trial. All visible weeds were removed. All beds had been cultivated once previously with a basket weeder mounted on a Tuff-Bilt cultivating tractor, removing most of the out-of-row weeds.

Given the controls above and a particular weed density, the weeding times for a particular method (prone, crawling) should be consistent. We assumed a Gaussian distribution of weeding time measurements, following these general observations: If weed pressure and the number of weeds were low in particular beds, hand weeding for those beds was less likely to be considered as a time-efficient task on the farm. Similarly, if weed pressure and or the number of weeds were too high, weeding would incur an unacceptable cost for preserving the crop, Thus, in our minds, there was the greatest probability of hand weeding taking place at moderate weed pressure and weed densities, with decreased incentives for farmers to engage in hand weeding at the extremes of weed pressure. The one exception to this assertion is what is sometimes referred to as “pulling trees”, where farmers or farm-workers pull a few large weeds from a maturing crop, usually where there is an opportunity to remove those weeds that will soon go to seed and consequently have a negative impact on future weed pressure in that bed. Because this task can be completed easily while simply walking down the bed, there would be no point in using the prone workstation for such a job, as the prone workstation is not intended to travel much faster than walking speed, and walking is not nearly as ergonomically stressful as weeding on hands and knees.

For our hand-weeding trials, we saw an average 28% decrease in the time spent per bedfoot hand-weeding a 3 row closely planted crop (in this case all the trials were baby lettuce) compared with crawling along the ground (hands and knees). This was equivalent to an average time savings of 19.7 minutes on a 400 foot bed. The standard deviation of the mean is equivalent to 7 minutes on a 400 ft bed. The 65% confidence interval is 13.7 min to 26.7 min saved per 400' bed. The 95% confidence interval is 5.7 min to 33.7 min saved per 400' bed.

Assessment and Adoption

As weed density on the bed became high, the time savings using the prone workstation became low as the benefit of simpler mobility on the prone workstation was lost because the number of weeds necessitated a speed similar to that of crawling on hands and knees. We saw the largest time savings when weed density was moderate to low, which capitalized on the added mobility of the workstation. We attribute the remainder of the difference to the use of both hands for weeding, Weeding was consistently described in anecdotal accounts as "far more comfortable" on the prone work platform than on hands and knees.

We consider this an effective vehicle for augmenting hand weeding efficiency on beds with moderate to low weed pressure. The main limitation with day to day use of the prone weeder has to do with the number of people available to weed a certain number of beds. If you only have one prone weeder (with two riders) everyone else on the crew that is also weeding does not see any ergonomic or efficiency benefit. Therefore the most benefit is to small scale farmers with a very small or no hand weeding crew (they do it themselves), or those farms that equip all of their farmworkers with a seat on one of multiple workstations, such that everyone is riding one. While the vehicle can be ridden by one rider, long arms are needed to cover all the rows of the bed. An alternative design might be to use one rider centered over the bed and a rear differential transmission from a go kart. In this situation, the combination of simulteneous steering and weeding three rows might counteract some of the efficiency gains realized in the two person model.

2.) Transplanting Trials

Activities and Results

We found that the human power output requirements for transplanting are very similar to that of hand weeding and easily met with human power. All of our hand transplanting on Arethusa Collective Farm takes place in teams of several people, generally at least two, and sometimes even 4 workers. We have a team of 2 people dibbling, popping flats, dropping out transplants at the proper spacing on the ground, and 2 others planting the transplants. The speed is comparable to that of a water wheel planter and tractor except for squash and other plants with wide spacing that allows quicker planting due to the tractor's speed. The tractor method can also get by with 1-2 fewer people working, resulting in labor cost savings.

In the first season of preliminary trials, the anecdotal findings for transplanting rates were inconclusive, sometimes faster than hand planting, and sometimes slower. We did the anecdotal tests while planting garlic in the fall, and found a few key issues that were addressed the next spring. Firstly, the crates attached to the vehicle and holding the garlic cloves were too deep and too close to the soil. This obstructed or obscured our view of the dibbles as they came into view, and sometimes resulted in wasted time searching for where to plant the cloves. Early in the spring we fashioned a new attachment tray to hold 3-4 150 cell transplant trays. This addition enabled us to carry the plants to be planted on the prone workstation, in front of the planters for easy access. After testing this setup out, we found that the speed gained by the prone workstation was lost due to the additional time it took get the starts out of the tray.

We then reflected on our experience planting the garlic cloves the previous fall. When the cloves had already been placed out on the ground at proper spacing ahead of us, the work was extremely fast, and we were able to maintain a significantly higher speed moving over the bed with the prone workstation. For this reason, the trials in the second season were modified to use this method and only replace the actual planting of the starts with the prone workstation. This meant that two individuals would be on the prone workstation or moving along the ground transplanting (depending on the type of trial, prone or normal), and two or three others would be popping trays, fertilizing/watering, dibbling, and dropping the starts at proper spacing. We then proceeded to add all of the labor time for these combined actions to get a measurement of labor-minutes per bedfoot (min./bed-ft). This also allows farmers to compare our two methods with the commonly used tractor-mounted water-planter and dibbler by adding the tractor and implement use costs to their total labor time and rates for transplanting.

In the 2008 season we conducted the transplanting trials. Relative efficiency measurements of prone transplanting were made in a series of 9 time-based trials. In each trial took place on sections of bed length between 58 feet and 786 feet. Prone transplanting or hand transplanting was measured in total labor minutes per bedfoot (min./bed-ft.), accomplished through the use of a stopwatch and a measuring wheel to verify each transplanted section length after the trial. The labor time for a trial included any time spent by individuals popping trays, fertilizing/watering, dibbling, dropping plants at proper spacing and planting the plants (by hand or by prone workstation). In several trials we also separately recorded the time for planting alone (normal or prone) and for the combined tasks of popping trays, fertilizing/watering, dibbling, dropping plants at proper spacing. The transplanting for comparative trials occurred on the same date, on an adjacent bed of the same succession of the same crop, or on a different portion of the same bed with the same succession of the same crop. Once again total labor minutes per bedfoot (min./bed-ft.) was recorded. This provided control for variations in crop type, weather, and soil conditions. Each person on the prone platform participated in both hand planting and prone planting trials to control for variations in personal planting speed. The order of trials within the workday was alternated to make an effort to control for fatigue levels. Subjective comfort levels were ascertained by noting the general feeling of the planters at the end of each bed. All beds had been prepared prior to planting, and the final pass on them was with a tractor mounted rototiller. Planters consistently felt that the vehicle was more comfortable than doing it by crawling and kneeling or standing and bending. The results are summarized in the table below. In the table below we converted minutes to seconds as it is easier to intuitively understand seconds than decimal fractions of minutes.

Crop and Planting Type	Plant spacing (in.)	Rows (#)	Number of Workers (#)	Planting Rate (plants/min., all worker labor)	Speed (seconds/bedfoot +/- 0.02 second)
Head Lettuce Prone *	12	3	2	7.2	25.09
Head Lettuce Normal	12	3	1	14.8	12.70
Head Lettuce Prone	12	3	2	16.2	11.11
Head Lettuce Prone	12	3	2	17.97	10.02
Head Lettuce Normal	12	3	2	12.27	14.67

Head Lettuce Prone	12	3	2	18.88	9.54
Head Lettuce Prone	18	2	3	14.42	12.48
Kale Prone	18	2	3	6.59	12.13
Cucumber Normal	18	1	4	4.37	9.16

*This attempt was performed with the method we determined in 2007 to be inferior, namely of carrying the trays on the vehicle and doing all operations in one pass over the bed. It is included for reference to show that there are actually efficiency losses (roughly 50% more labor time than normal) if this method is used. Its data point is not included in the discussion below.

The average for the prone trials was 11.05 seconds/bedfoot +/- 0.02 seconds, The average of the normal trials came out to 12.18 seconds/bedfoot +/-0.02 seconds. Over a 400 foot bed the actual differences in time for the averages amount to 7 min. 28.8 seconds +/- 7.8 seconds. This results in an average 9.22% +/- 0.16% decrease in planting time. The number of samples is not significant enough for statistical analysis to verify that this margin is statistically robust, but should give users an indication of what can be expected.

Assessment and Adoption

While there is a roughly 9% efficiency benefit that reduces labor time in transplanting, the primary benefit in transplanting on the prone workstation is ergonomic. With tow-behind-the-tractor water wheel planters and other types of mechanical transplanting devices, this type of vehicle can be of use if those other vehicles are not available or if all transplanting is currently done by hand.

3.) Cultivation Experiments

Activities and Results

During the 2008 season Arethusa Farm acquired a Kubota High Clearance tractor primarily for cultivating crops. The original trials scheduled for 2007 and rescheduled for 2008 were intended to compare the quality of cultivation between the Tuff-Bilt cultivating tractor and the prone workstation. With the arrival of the Kubota on the farm, we no longer rented the Tuff-Bilt cultivating tractor. It quickly became clear that the Kubota was more powerful than the Tuff-Bilt and significantly out-classed the pedal powered prone workstation. The Kubota was powerful enough for all the tasks on the farm except primary tillage, and we determined that comparing it with the prone workstation was not a valuable endeavor, as they were really intended for entirely different purposes. In 2008 we therefore reduced the scope of cultivation trials and instead performed tests to determine the limits for pedal powered cultivation with respect to this vehicle.

We made an effort to characterize the magnitude of the force we could expect to devote to pulling an implement through the soil. To do this, we created a whole-bed stale seeder attachment in the form of a spike tooth harrow. The harrow spikes had a combined cross sectional area of 39.3 square inches. The harrow was constituted of 37, ¼ in. diameter spikes, arranged in three offset rows to cover the 48” width bed top, and dragged at a depth of 4.25 in. over a previously spring-tined soil. At this depth, the total spike protrusion of 4.25 in. was fully inserted in the ground. The depth was not controlled, as the attachment was dragged by rope from two hitch points at the rear of the vehicle. The harrow maintained its depth reliably but did build up some crop residue and weed material on its front edge. At maximum personal effort we were able to pull the harrow one hundred and twenty feet before we felt fatigued. This puts the harrow usage at the upper limit of power outputs for average fit and healthy humans.

The test with our spike tooth harrow suggests that any cultivation tool requiring more than 0.45 kN (kilo-Newtons or 450 Newtons) of specific draft force is not feasible with two riders for more than a few minutes. The estimated the total human muscle power output to achieve this is on the order of 500 +/- 100 Watts, or 0.67 +/- 0.13 HP, and puts a reasonable upper limit on the cultivation tasks that can be attempted with two riders on this vehicle. The amount of power output for this cultivation task was not sustainable, but we were successful in dragging the spike tooth harrow.

Assessment and Adoption.

We believe that that several cultivation tasks can be successfully and reliably completed with the available human power. In our sandy loam, with just one rider powering it, we were easily capable of using two 6” co-linear hoe blades situated at a depth of 1-2” to breakup and uproot small (2” tall and smaller) weeds. With two riders, and sufficient co-linear style blades, we are confident that we could easily cultivate the un-cropped portions of a 48 inch wide bed.

As news of our research has spread, some of the individuals who have contacted us were in fact interested in a quadracycle to replace small cultivating tractors. The chief concern with human-powered cultivation is the amount of force needed to draw tools through the soil, and the land we work on is flat, sandy river-bottom soil, ideal for cultivating with low horsepower inputs.

The machine best suited to accomplish this feat may be, we feel, something entirely different from where our prone workstation design has ended up. We have imagined, based on our work this past season with pedal-power in the field, that such a vehicle may require the addition of electric assist to human power, possibly with a photovoltaic shade, to supply the required power output over a sustained period of time. Such a vehicle could be tooled up to sweep a crop, stale a seedbed, or perhaps even be outfitted with some variation of the Buddingh basket weeder. It could also serve as a small Un-interruptable Power Supply (UPS) out in the field with a small inverter on board.

For there to be comparable efficiencies in person-hours between human-powered and tractor-powered cultivation, the vehicle must be designed for use by a single operator and would likely resemble an Allis-Chalmers G cultivating tractor in appearance. The upright seating of a normal bicycle or tractor is also desirable for increased acceptance by farmers.

In 2009 Rob Rock left Arethusa Farm and went on to become the co-owner of Pitchfork Farm, also on the Intervale in Burlington. With only 4 acres under cultivation and a crew of only three workers, this farm situation and size is more or less what was in mind when the grant project was undertaken. New modifications will continue on our design and we will resume trials in the field.

As our design and fabrication skills have improved it has also become clear that a more simple frame geometry might be possible. A new design could potentially be lighter, cheaper, and easier to build. Some of our interest in this area is related to our belief that pedal-powered prone workstation could one day become a marketable product desirable to other small-scale growers.

Economics of the prone workstation

A common method when considering the value of purchasing new tools and equipment is to determine how many seasons it would take for the new purchase to pay for itself. On many of the small farms we have visited it is almost always the case that there is a sizable amount of both transplanting by hand and weeding by hand done by the crew. Attached is a separate document named "SARE-FNE07-603_simplepayback.xls" It is a spreadsheet to calculate simple payback. This spreadsheet is useful in determining the simple payback for implementing a prone workstation of similar design on your farm. While simple payback is not an extremely useful measure of investment, it can help you decide if this tool would make a meaningful impact on your farm. Fill in the outlined boxes and the spreadsheet will calculate the simple payback. It takes into account the fact that only two people can ride a single vehicle, and that with a large crew and one vehicle, the speed benefit is only for two riders. Fastest paybacks occur when there is one vehicle for every two riders and more work hours on average per week spent on both the tasks of weeding and transplanting.

Over the past two years the maintenance costs have amounted to three new bicycle chains for $36.00, two welding repairs $40.00, and $4.00 in replacement hardware. That averages out to a yearly upkeep of $40.00 in materials and labor.

It is more difficult to put a number on the avoided long term musculoskeletal injury in a more ergonomic work position. Because our seat design has significant room for improvement, and has not been proven to reduce musculoskeletal stress or prevent injury, we do not make any claim of savings. We will simply point out that people find riding this vehicle far more comfortable and satisfying than crawling along the ground for hand weeding or transplanting.

Outreach

During the period of time in which we were fabricating and trialing the vehicle there were countless opportunities to demonstrate our work to the farmers of the Intervale. At the peak of the season there may be as many as 75 farmers and their employees on the Intervale, and with our workspace located in a place which was central to farmer activity it was easy for us to share our work.

Some of our outreach work was both informal and unexpected; as news of what we were doing spread we had some visitors drop in on us. For example we made a presentation to Plant and Soil Science professor Sid Bosworth's "Weed Management" class from the University of Vermont. Students were able to test the vehicle and ask questions about the ergonomics and utility of our design, and we gave them a brief talk on the role of hand-weeding in small crop organic weed management.

On two separate occasions, students from Burlington College, Nicole Seligson and Andrew Meyers—both who were interested in human power on the farm—came down to the Intervale to interview us for papers they were writing and projects they were working on, respectively. Nicole spent a part of this last winter visiting Maya Pedal in Guatemala, an NGO dedicated to building "bicimaquinas" or bicycle machines for small-scale and sustainable projects which are often directly related to agriculture. For instance they have designed and developed a number of human-powered grain mills (www.mayapedal.org). Nicole will be returning to the Intervale this summer and we are looking forward to working with her on any pedal-powered projects she might try and tackle. Andrew Meyers established a relationship with Rob and the two will be working together this season on Pitchfork Farm. Andrew Myers is in the process of designing and building a human powered greens harvester, and we are all excited to test the prototype.

One of our most interesting group of visitors was perhaps the Women's Garden Cycles Bike Tour.

The group was comprised of Liz Tylander, Kat Shiffler, and Lara Sheets, who were riding from Washington D.C. to Montreal and back with the intention of visiting urban agricultural settings along the way and gathering material for a documentary film they were putting together. We were interviewed and received a write up on their blog (http://womensgardencycles.wordpress.com/) and appeared briefly in their documentary film "Garden Cycles".

During this last winter we applied for and were awarded a residency in a community workshop space at Pine Street Studios. We used this time to make adjustments to the prototype of the prone workstation, as well as to build other human-power related projects. One of the machines we developed was a quadracycle human powered tractor which puts the operator in an upright position using frame geometry similar to a mountain bike, but in place of handlebars, the steering is done with a steering wheel. The purpose of this machine is to drive a gang of Earthway seeders over a bed so as to plant tightly spaced rows of greens.

As the culmination of our residency, we hosted an event on March 20th 2009 to present our work, and we were able to invite other community members who had built human-powered vehicles to join us. In attendance were primarily vegetable farmers and bicycle enthusiasts from the area, but the occasion also allowed individuals to ride the vehicles we had created, as well as show the vehicles to folks who were associated with the arts, with engineering, and the University of Vermont. We were encouraged by the broad spectrum of individuals who were interested in human power on the farm.

Although we have not completed a serious examination of the question, the possibility of one day producing and marketing human-powered farm machinery is slowly being explored. It is our hope to continue to refine and develop more reliable tools, and to carry our outreach efforts into the future. As a record for the farming community we will be hosting the website http://www.farmcycle.com where interested farmers can keep up to date with our latest equipment designs, tests, and trials.

On a lighter note, pedal power on the farm is a notion almost everyone seems to appreciate and enjoy. Nearly everyone we have met who has tested the vehicle cannot help but smile. The reasoning behind decisions made on a serious for profit farm operation must be practical, but in this case there is also the reminder that so much of what we do when we produce food can bring people joy.

Financial Report

See attached file "Projected budget and final financial report SARE FNE07-603.xls"

Report Summary

Many of the activities done by hand on a small vegetable farm could be accomplished in a more efficient and ergonomic manner with the implementation of simple tools. The tasks which we most closely examined were hand weeding and transplanting, and the simple tool we used to improve these tasks was a human powered quadracycle which put the operator in a prone position as they pedaled over the crops. The results of our experiment confirmed that there were efficiency and comfort gains realized as a result of our design for a "human powered prone workstation".