Project Title:
A New Appropriate Technology Machine System to Benefit the Sustainability of Local Organic Vegetable Production

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Cooperators:
Erik Walles, Berries on Bryan Station, Fayette County, KY. Mr. Walles has farmed full time for nine years, growing a wide variety of organic berries and vegetables with his wife on their 10 acre farm a few miles north of Lexington, KY. Their farm has been certified organic since 2009. He has sold produce directly to local retail outlets and restaurants and through farm stands, farmers markets, and a community supported agriculture (CSA) operation. He has cooperated with agriculture researchers from the University of Kentucky on a number of different organic vegetable production projects.

Tiffany Thompson, Horticulturalist, Horticulture Department, University of Kentucky. Ms. Thompson is the manager for the Community Supported Agriculture (CSA) operation at the UK Horticulture Research Farm. This CSA is certified organic and serves over 150 subscribers in the university and local community. Student interns and workers from UK’s Sustainable Agriculture degree program provide most of the labor for the CSA.

Delia Scott, Fayette County Extension Agent for Horticulture, University of Kentucky Cooperative Extension Service. Ms. Scott helped coordinate the field day demonstration at Erik Walles’ farm.
Summary

A new version of a three wheeled machine using furrow guidance was designed and built and used to grow organic vegetable crops on a cooperating farm. It was also demonstrated during a field day. Production limitations made it difficult to assess labor requirements for the system in comparison to conventional organic production, but various new applications were explored during the on-farm work. Design plans for the new prototype of the machine have been developed and posted on-line. The new machine and associated implements cost approximately $5000 in materials and parts, and would likely cost twice that to have built.

Introduction

The increased popularity of fresh, local foods has contributed to a steady increase in Kentucky of the number of market growers, farmers who sell the bulk of their produce through farmers markets, to restaurants or through small retail outlets, or through community supported agriculture (CSA) (Woods, 2013). This increase in the actual number of farmers, rare among the different facets of agriculture, has been a bright spot in Kentucky and many other states. However, market growers face many challenges that limit their potential for achieving a sustainable level of economic viability in their farming operations. Chief among those challenges is the very high time/labor requirements for market vegetable production. Most market growers are small producers and cannot afford to hire much labor or to invest much in mechanization, so many are caught in a vicious cycle of over-work, unreliable production, and lack of profitability that has caused some growers to quit (Wilhoit, personal experience).

Organic production has the potential to bring higher returns for market growers, but growing organically has particular production challenges. Weed control is the biggest challenge since the use of herbicides is prohibited. There is an acute need for relatively low cost mechanization that specifically addresses the challenges faced by market growers producing organic vegetables, to help them improve the efficiency of their operations and therefore enhance utilization of available labor resources. Such mechanization can help smaller growers overcome production challenges and therefore expand their operations, achieving the reliability of production that is needed for them to tap into institutional and wholesale markets, improving the economic sustainability of their enterprises.

We have developed a low-cost, mechanized machine system that specifically addresses the challenges of small-to-intermediate scale organic vegetable production.
This appropriate technology system combines a wide-stance, three-wheeled prime mover with furrow guidance to give repeated precision in machine positioning for vegetable production operations throughout the course of the growing season, without the use of expensive GPS technology. It is especially effective for the precision mechanical cultivation necessary to control weeds in organic vegetable production, and the furrow guidance frees the driver to perform other tasks, improving the effectiveness of various manual operations and reducing labor requirements.

The furrow guidance machine system and various applications for it were developed during two years of work using an old three-wheeled tobacco harvesting aid retrofitted for furrow guidance. That work proved both the furrow guidance concept and the potential for bare ground production of certain crops (with buried drip tape, but without plastic mulch covering the bed). The unique way that the system works opens up a host of possible applications for a whole new type of intensive vegetable crop production. For this project, a new prototype of the machine, incorporating improvements in design both in terms of functionality and minimized fabrication costs, was designed and built for a private organic grower and used on his farm for exploring applications and functionality of the machine system as well as for demonstrating it to the public.

**Objectives/Performance Targets**

The main objectives of this project were to test this machine system in an on-farm, organic production setting and to introduce the technology to the public. Specific objectives were as follows:

1. To design and build a new version of the machine incorporating improvements and up-to-date components, for use in on-farm trials with a cooperating grower (machine components paid for by the grower, with grower retaining ownership).

2. To assess the performance of the furrow guidance system in growing organic vegetable crops in terms of labor requirements and crop production, in comparison to conventionally grown organic crops.

3. To assess the economics of the furrow guidance machine system used for organic vegetable production.

4. To introduce the furrow guidance machine system to market growers and others through a field day demonstration and other outreach activities.

5. To develop design plans and specifications for the machine system for posting on-line in an open source environment.
Materials and Methods

New Machine

The new prototype designed and built for this project uses the same basic configuration as the original prototype, with a single drive wheel in the, an electric lift on one side (with Cat. 0 three point hitch), and adjustable widely-spaced steered wheels in front that straddle two vegetable rows. It has mechanical steering that allows feedback from the guidance arms so that the furrows created by the narrow front wheels can be used for precision guidance for repeated operations over the same rows. The new design kept the basic configuration of the original prototype, as well as the primary objective of being low-cost and relatively simple mechanization, while incorporating a few improvements. One improvement was higher frame clearance, both for crops and to allow implements to extend under the center beam of the frame. The clearance under the front frame of the new prototype is 30”, compared to approximately 22” with the old machine. Another primary improvement was to make the row spacing of the front steered wheels adjustable in specific 3” increments (accomplished with a pins inserted into a series of drilled holes in the sliding tubes used for the front part of the frame). The range of row spacings for the new machine was the same as with the old machine, from a minimum of 36” to a maximum of 48”, but the use of the set increments meant that it was much easier to make adjustments between different row spacings. The use of the pins in the holes also set the placement of the three-point hitch lift exactly halfway between the center of the drive wheel and that of the steered wheel. One more important improvement in the new machine was the use of the front part of the frame as the toolbar for mounting the lift and operator seat. The new prototype is shown in Figure 1 with labels for some parts of the machine.
Figure 1. New prototype of the three wheeled machine with furrow guidance.

On-Farm Research Trials

Three organic vegetable crops, potatoes, beets, and broccoli, were grown using the furrow guidance machine system with cooperating farmer Erik Walles on his farm, Berries on Bryan Station, located just a few miles north of Lexington, Kentucky. In each case, the furrow guidance system was used to plant four machine rows (two machine widths) of approximately 200’ length, for a total machine row length of 800’, at a machine row spacing of 42”. Conventionally grown organic plots (grown without using the furrow guidance system) were grown in the same field at approximately the same time. An attempt was made to have approximately the same area of crop production for both the furrow guidance and conventional organic plots, but space limitations necessitated planting only half as much area for the conventional organic beet crop.

Potatoes  Potatoes were planted using the furrow guidance system on May 7, 2015. The older prototype of the machine was borrowed from the University of Kentucky and used for planting potatoes, as the fabrication of the new machine was not yet completed. The potato seed pieces were planted approximately 12” apart into flat ground in the furrow created to bury a single line of drip tape for each row (approximately 4” deep), with the furrow closed by a chain pulled over the soil by the drip tape laying attachment. The seed pieces were planted in a one-person operation, with the operator dropping the seed pieces through a planting tube into the furrow, as no steering was required because of the furrow guidance. The rows of potatoes were
hilled using hilling disks (using the new three-wheeled machine) in a later operation. For the conventional organic plots, two raised beds on 6’ centers were made using a raised-bed plastic layer that laid a single row of drip tape but did not cover the row with plastic mulch. Potatoes were planted into these raised beds by hand, using a planting knife, on May 8, 2015. Two rows approximately 15” apart were planted into each raised bed, for the same row length, in the same approximate area, of potato production as the furrow guidance plots.

**Beets** Beets were planted using the furrow guidance system on June 9, 2015. The beets were direct seeded in double rows 11” apart, centered over the buried drip tape, using a pair of Jang seeders pulled by the three-wheeled/furrow guidance machine (the new version). This was done on four rows of drip tape, the same row length and area as used for the potato plots (800’), but an actual planted beet row length of 1600’. The Jang seeders were set to seed on approximately 3” seed spacing, although the exact seeding rate was not determined. For the conventional organic beet plots, raised plastic-covered beds were created using a plastic layer implement, and holes were punched in the plastic using an implement with a set of hole-punch dibble wheels. Then seed was dropped into each hole by hand. The conventional organic beet plots were seeded on June 17, 2016. The raised plastic-covered beds had a single line of drip tape down the middle of the bed, and holes were punched in double rows approximately 11” apart centered over the buried drip tape using a dibble wheel implement pulled by a tractor. In Erik Walles’ field, only enough space was available for about 400’ of length of plastic-covered beds for the conventional organic beet plots, half the row length used for the furrow guidance plots. Because of the greater row spacing with the plastic-covered beds, the area per length of row was about the same for both plots, but the number of planting locations was considerably lower for the plastic-covered rows. In an attempt to make up for the difference, the number of beet seeds dropped in each location was increased to four, with the reasoning that multiple beets would be able to form in each hole punched in the plastic.

**Broccoli** For the broccoli plots, the three-wheeled machine was first used to apply organic fertilizer (Nature Safe 8-5-5) at a rate of approximately 100 lb actual N/acre to both the furrow guidance and the conventional organic plots using an implement with an electric-powered fertilizer drop box (powered off the machine battery). The three-wheeled machine was then used to lay four 200’ long rows of drip tape in the furrow-guidance plots. After the water was hooked up to the drip tape lines and run long enough to wet the soil, broccoli seedlings were transplanted into the furrow guidance plots on August 25, 2015 using the three-wheeled machine with furrow guidance, with seedlings planted manually from the operator seat of the machine. For the conventional organic broccoli plots, two 200’ long raised plastic-covered beds were created using a plastic layer, with a single line of drip tape down the middle of each bed. Holes were
punched in double rows approximately 11” apart centered over the buried drip tape using the dibble wheel implement pulled by a tractor. Broccoli seedlings were transplanted into these holes on the same day that they were planted in the furrow guidance plots, August 25, 2016.

Operational Trials at University Research Farm

The original version of the three-wheeled machine with furrow guidance was used at the University of Kentucky Horticulture Research Farm to grow crops of potatoes and lettuce with student workers from the organic section of the farm operating the machine. The crops were grown organically, although they were not grown in the section of the farm that is certified-organic. The furrow guidance machine was used to plant six rows of potatoes 300' long, at 42” row spacing, on May 13, 2015. The potato seed pieces were planted approximately 12” apart into flat ground as the drip tape was being laid. Planting (and running the machine) was done by five different student workers in planting the six rows. The three-wheeled machine was used to lay four rows of drip tape for lettuce on May 13, 2015. The next day, after the water was hooked up to the drip lines and run long enough to wet the soil, lettuce seedlings were transplanted in single rows over the buried drip tape, at an in-row spacing of approximately 8”. Three different student workers planted the first row, and then a different student planted each of the remaining three rows. The furrow guidance machine was used on several other occasions to cultivate both the potato and lettuce crops at the research farm, with student workers operating the machine each time. It was also used for two other operations with the potatoes that were not done by student workers, hillling and side-dressing with organic fertilizer. The time required for the operations with the furrow guidance machine at the research farm were recorded, and the student workers were asked to give their impressions about the machine and to make suggestions for improvements.

Results and Discussion/Milestones

On-Farm Research Trials

The on-farm research activities conducted as part of this project yielded much useful information about applications and limitations of the furrow guidance machine system, but there were significant problems with the crop trials that limited the amount of data pertinent to assessing labor requirements and economics. The problems were largely the result of production restrictions due to both the physical and marketing situations of the farm where the on-farm work was done, in combination with the nature of the furrow guidance system. The furrow guidance system needs relatively flat ground, and it benefits from larger field areas because of the non-productive time making turns at the
ends of the rows and the guidance provided by the furrows for adjacent machine passes across the field. The only area of Mr. Walles’ farm meeting those requirements was a flat area that, due to previous history, had poor soil structure with a very low level of organic matter. Mr. Walles markets primarily to restaurants on a weekly basis, relying on consistent production over a long period. He had no way of marketing produce from the kind of larger-scale, more concentrated harvests that would give more useful data on both yields and labor requirements. Finally, because of how the furrow guidance system works, and its capabilities for cultivation, it was essentially impossible for Mr. Walles to grow the “conventional” organic plots in the same way as the furrow guidance plots, so compromises that had to be made in how the conventional organic plots were grown made meaningful comparisons of the results difficult.

**Potatoes** The furrow guidance potatoes were planted into flat ground in a one-person operation, dropping the seed pieces down a tube into the trench directly above the drip tape, as the drip tape was being laid. In the conventional plots, a raised-bed plastic layer implement was used to lay the drip tape and raise a bed in one operation first (without laying plastic mulch), and then potato seed pieces were manually planted in double rows (one to either side of the drip tape) in a separate operation, using a planting knife to make the openings for the seed pieces. Approximately 1200 potato seed pieces were planted in each of the furrow guidance and conventional organic plots. It took 81 minutes to plant the 1200 seed pieces manually into the two raised beds of the conventional organic plots. It took 55 minutes to plant the same number of seed pieces in four rows of the furrow guidance plots. It was noted that because problems with the engine limited the speed of the machine (the old three-wheeled machine was used for planting potatoes), it would have been possible to plant potatoes in the furrow guidance plots approximately 30% faster. If it had taken 40 instead of 55 minutes, it would have taken twice as long to plant seed pieces manually (81 minutes) as it did with the furrow guidance machine system. Plus, an extra operation for laying drip tape was required for the conventional plots. Also, it was noted by Mr. Walles that, while he could plant 1200 seed pieces manually in 81 minutes, there is no way that he could have kept up that pace for many hours, while it would have been easy to plant potatoes all day long with the furrow guidance system.

Additional operations were conducted on the potato plots with the three-wheeled machine, including two cultivations and one hilling operation. Mr Walles did not have a good way to cultivate the conventional plot potatoes planted into the raised bed, but he was able to perform a hilling operation on them using a single-side belly-mounted disc on a Farmall 140, which helped some with the weeds. The potato plants in both the furrow guidance and conventional plots did not thrive, presumably because of the poor soil conditions, and they suffered a severe potato beetle infestation despite treatments with organic insecticide. Mr Walles tried using row covers to exclude potato beetles
from the conventional plots (they could not be used on the furrow guidance plots because it would have impeded cultivation operations). Several hours were spent picking potato beetles and eggs off the potato plants by hand in the furrow guidance plots, but the damage was too severe for the plants to recover. Because of the row cover, the potato plants in the conventional plots did not suffer as much insect damage, but the plots became exceedingly weedy because of the lack of cultivation. Potatoes were finally dug from the conventional plots on August 20, 2016, using a middle-buster plow on a full sized tractor, but it was a essentially a crop failure as the amount harvested (32 lbs.) was just a fraction of the weight of seed potatoes planted. The three-wheeled machine was used to try digging potatoes in the furrow guidance plot, using the digging shoe of the drip-tape laying implement. The digging operation seemed to work, but it was difficult to assess how well it worked because there were so few potatoes, even less than in the conventional organic plots (9 lbs.).

**Beets** For the beet trials, Mr. Walles realized that it would be nearly impossible for him to keep the weeds down in conventional organic plots if they were direct seeded into bare ground, as in the furrow guidance plots. He had successfully grown beets in the past using raised, plastic-covered beds with beet seed planted in holes punched through the plastic, so he decided to do that for the conventional organic plots. Because of space limitations in the area of flat ground used for the trials, only 400’ of raised beds could be planted, half the length of machine row planted in the furrow guidance plots. The beets were not seeded into the raised beds until June 17, 2016, eight days later than they were direct seeded in the furrow guidance plots using the Jang seeders. The same seed was used in both plots, but for some reason, probably related to weather/soil conditions and the microclimate created inside the black plastic, the germination in the conventional plots was very much lower than in the furrow guidance plots.

Planting beet seed with the three-wheeled machine using the Jang seeders was very fast, approximately 20 minutes to do 800’ of machine row. For the conventional organic plots, it took Mr. Walles 15 minutes to punch the holes in 400’ of plastic-covered bed using the hole-punch drum implement, and then 60 minutes for him the place the beet seed in the holes. Both plots required separate operations prior to seeding, for laying drip tape-only in the case of the furrow guidance plot, and for raising the bed and laying plastic mulch in addition to drip tape in the case of the conventional organic plot.

The furrow guidance beet plots were cultivated twice using the three-wheeled machine. Mr. Walles began harvesting beets from the plots in early July, and continued harvesting a small amount weekly throughout the summer and fall. He prefers spreading out the harvest over a long time period because of his marketing outlet, and finds that the beets stay in salable condition for a much longer time when left in the
ground (as opposed to being held in cold storage). Because the beets were harvested in this way, we were not able to try out the three-wheeled machine for digging beets, or as any sort of harvesting aid. It should be noted that the two cultivations provided adequate weed control for the beets to be left in the ground for a period of several months. A total of 199 lbs. of beets were harvested from the 800’ of machine row in the furrow guidance plots, while only 9.1 lbs. were harvested from the 400’ of raised bed in the conventional organic plots.

**Broccoli** Broccoli seedlings were planted in late August, more than two weeks later than the target planting date, because of problems with the production of the seedlings. Mr. Walles had not previously done outside production of transplanted crops in the fall, and he was not well-set up for producing the transplants. As with the beets, Mr. Walles decided that it would be nearly impossible for him to keep the weeds down in the conventional organic plots if the broccoli seedlings were transplanted into bare ground, as in the furrow guidance plots, so the decision was made to transplant them into raised, plastic covered beds. Both plots required separate operations prior to planting, for laying drip tape only in the case of the furrow guidance plot, and for raising the bed and laying plastic mulch as well as drip tape in the case of the conventional organic plot. Transplanting broccoli seedlings in the furrow guidance plots from the three-wheeled machine took 102 minutes. In the conventional plots, punching holes took approximately 15 minutes, and transplanting into those holes took 78 minutes.

Initial growth of the broccoli transplants was slow in the poor soils where they were planted, and it seemed likely that they would not have time to produce marketable heads before a hard frost. But we had unseasonably warm weather in central Kentucky up through the end of December, and we eventually ended up getting a decent crop of marketable broccoli heads from both the conventional organic and the furrow guidance plots.

The three-wheeled machine was used to cultivate broccoli in the furrow guidance plots on three different occasions, and weed control was fairly good. The growth of the broccoli plants in the conventional plots (in raised, plastic-covered beds) appeared to be better earlier in the season, and the heads in these plots were in fact large enough to be harvested one to two weeks earlier than those in the furrow guidance plots. Also, survival of transplants appeared to be slightly better in the conventional organic plots than in the furrow guidance plots. The first heads of broccoli were not harvested in the conventional plots until late November, and not in the furrow guidance plots until the first week of December. The broccoli harvest continued throughout the month of December. The amount of broccoli harvested from the furrow guidance plots was 149 lbs., and 173 lbs. was harvested from the conventional organic plots. As with the beets, it was not possible to derive the benefit of using the three-wheeled machine as a harvest aid, as
would work with a more concentrated harvest. We had done this successfully in the past, and we tried it out briefly with Mr. Walles as a demonstration to show him how it works.

**Operational Trials at University Research Farm**

These trials at the university research farm were used to gain more experience using the furrow guidance system operationally and to get feedback from a wide range of users of the machine system. The first prototype of the machine was used for these trials, and there were issues with this old machine that affected its operation. The engine was not running well, control levers for engaging/disengaging the clutch and braking the machine do not work well in coordination, and the toolbar can become skewed over time. Some of the student workers were intimidated by the machine, and found it difficult to coordinate the machine operation with their responsibilities while riding the machine (raising and lowering the lift, planting potatoes or transplanting lettuce). Some of the larger students had trouble with the old seat on the machine. The experience gained in these trials led to subsequent improvements in the older prototype including tabs welded onto the mount of the toolbar to prevent it from skewing, and the purchase and mounting of a new seat.

Despite some of these issues, most of the student workers did fine operating the machine and liked how it worked. Most of them were able to operate it safely and effectively after only a brief explanation and demonstration. One interesting suggestion that the students made was to incorporate some way of engaging/disengaging the machine with some sort of lever or switch that could be activated by foot.

The potatoes at the research farm were cultivated three times using the furrow guidance system. The machine system was also used to hill the potatoes, and to side dress them with fertilizer. Side dressing was accomplished using an old electric-powered fertilizer drop box rigged up to the cultivator implement. The development of this implement was prompted by Tiffany Thompson, the manager of the organic section of the research farm, as she realized that the field used for potatoes had not been fertilized and needed side-dressing. The potatoes were grown using all organic practices (although not on ground certified organic), and produced a good crop (although yield data was not available at the time that this report was written and submitted). The lettuce was also cultivated three times. The lettuce plants grew well, but they were not harvested because they were planted too late in the season and bolted.

**Additional Work on Implements/Applications for Furrow Guidance Machine System**

During the course of the work for this project with both the old and new prototypes of the three wheeled machine, several new applications were developed or explored. The
need to fertilize the potatoes grown at the university research farm prompted us to rig up an electric-powered fertilizer drop box with tubes for dropping organic fertilizer in front of the cultivator sweeps. The electric motor was powered from the three-wheeled machine battery. This implement worked well side-dressing potatoes, and was later used for applying fertilizer to both the conventional organic and furrow guidance plots prior to transplanting broccoli at Berries on Bryan Station farm. Note that for the pre-plant fertilization using organic fertilizer, the maximum application rate of the drop box was insufficient to apply the required amount of fertilizer in a single pass, so it was done in multiple passes.

The idea of using the three wheeled machine with plastic-covered beds was explored. The spacing of the new prototype was changed to an unsymmetrical configuration, with the passenger (implement) side moved out to the maximum 48" spacing and the driver side moved in to the minimum spacing of 36". The idea was that the machine could straddle a row of plastic on the wide side, with the plastic-covered row between the steered and traction wheels, while on the narrow side the steered and traction wheels would both be in the same space between two plastic-covered rows. The machine was tried with this configuration on some existing plastic-covered rows spaced on 10’ centers at Mr. Walles’ farm. At first the machine was tried driving over the row to see if the spacing would work. It did. Then it was driven with the passenger-side guidance arm down, with the guidance wheel near the edge of the plastic, with the furrow-reforming shovel attempting to dig a furrow. The machine was then driven back over the same row using the furrow for guidance. The guidance arm followed the furrow for the most part, but it did come out on a couple of occasions. The space between the rows of plastic had been seeded in grass earlier in the season, so it was difficult to dig a good furrow in the established sod. It seemed like there was good potential for the furrow guidance to work reliably if good quality furrows could be formed when the plastic was laid initially.

The above trials were done with existing plastic-covered beds that used 48” plastic. The current three-wheeled machine is not near large enough to handle plastic layer implements that lay 48” plastic, so we tried the machine using a small plastic layer implement for walk-behind tractors that can lay 36” plastic. This plastic layer is designed to lay plastic on a flat bed. We tried out the new machine at the university research farm laying 36” plastic. It worked fine rolling out the plastic, but we had a hard time getting things adjusted so the edges of the plastic were adequately covered. One other thing that was tried related to plastic-covered beds was to rig up the dibble wheels to a toolbar for the three wheeled machine for punching holes in plastic. Further work is needed to explore the application of using the three-wheeled machine with furrow guidance for plastic-covered rows. This could be an important application for growing certain crops.
The three wheeled machine was tried for pulling buried drip tape at the end of the season by tying the drip tape to the frame of the machine, to see if it would have any advantages over pulling drip tape manually. Where this application was tried, the drip tape had been buried a long time and the soil was firmly compacted, making it difficult to pull out the drip tape without it breaking under tension. The problem with the drip tape breaking was just as bad with the three-wheeled machine as it was using other methods. However, it should be noted that this was drip tape that had been laid some months earlier for demonstration purposes (with no crop grown), and as such there were no existing furrows to reference where the drip tape had been laid. If there had been, the digging shoe of the drip tape layer could have been used to precisely loosen the soil above the buried drip tape, making it much easier to pull it up. It might even be relatively easy to incorporate a reel for winding up the drip tape as it is pulled, for easier disposal or for possible reuse. Since the furrow guidance machine system is for bare-ground production with buried drip tape, being able to use it to facilitate drip tape removal operations could be a very beneficial application.

In addition to the efforts with the fertilizer drop box, other work was done mounting tools on toolbars for using with the Cat.0 three-point hitch of the three wheeled machine. In previous work with the furrow guidance system, an implement had been rigged up for operating a pair of older model Planet Junior seeders with the three wheeled machine. For this project, the mounts were changed so that a pair of Jang seeders could be operated with the machine. A mount was also worked out for the dibble wheel that can be used for punching spaced planting holes in plastic covered rows. These and previous efforts have shown that the furrow guidance machine system has very good versatility for a large array of crop production applications.

**Impact of Results/Outcomes**

The direct results of this study are somewhat limited. This study has contributed to two farmers now having the furrow guidance machine technology with plans to use it for vegetable production in coming seasons. It has introduced the technology to a number of other producers and to various research and extension professionals as well as to members of the general public. It has also resulted in the internet posting of design plans and drawings for the three wheeled machine that people can use to build a machine themselves, or hire someone to build it for them. Indirectly, the results of this study have significantly increased the base of experience and knowledge about using furrow guidance technology for the production of various vegetable crops. It has led to the development of new applications such as applying fertilizer and laying plastic, and
has inspired new ideas for other applications including pulling drip tape, applying compost and mulch, and weeding between plants within the row.

Because of various challenges and constraints with the study related to production and marketing conditions, the on-farm research was not able to thoroughly document labor or cost savings from the use of the furrow guidance system in comparison to conventional organic production. Substantial labor savings were recorded for important operations such as planting potatoes and direct seeding crops, however. Also, it was shown that the system could be efficiently and effectively used to control weeds in a bare ground production system with buried drip tape. These results are important because they give an indication that the use of furrow guidance technology could offer an alternative to conventional organic vegetable production using plastic-covered beds. It is an alternative that not only has the potential to reduce labor requirements, allowing smaller-scale operations to increase their scale of operations in order to expand market opportunities, but also to improve sustainability and reduce costs by eliminating the use of petroleum-based plastic film mulches and allowing increased production from the same area of land (because of narrower row spacing).

**Economic Analysis**

The cost of materials used for the fabrication of the three wheeled machine with furrow guidance and for many of the implements are listed in the Parts List Spreadsheet posted as part of the machine design plans. (See supporting material for copy of parts list spreadsheet). The total cost for purchased parts and materials for the machine that we built was $3372 excluding the three point hitch lift, $4008 including the lift. The machine was built using some parts and materials that were not purchased and therefore not included in that total, including a drive wheel and hub that was surplus from the Biosystems and Agricultural Engineering Department, a few miscellaneous small parts, various nuts and bolts, and some steel from the machine shop where it was fabricated. We estimate that if we had purchased all of these materials, the total would have been approximately $4400. Another $447.32 was spent on parts for making three implements including the hilling discs, the cultivators, and the drip-tape layer. The fertilizer drop box that was used with the cultivator was surplus and not purchased. If the amount spent towards parts for implements was $600, the total for parts and implements would be $5000. To hire a machine shop to build a machine might be expected to cost an amount comparable to the cost of parts and materials, bringing the total cost to approximately $10,000.

In the on-farm research trials, the three wheeled machine was used to grow 800’ of machine row of each of three different crops, potatoes, beets, and broccoli. The potato
crop was a failure so we do not have a measure of the crop value for potatoes, but we do have marketing records for the production from the beet and broccoli trails. Mr. Walles’ marketing records show that the value of beets sold from the furrow guidance plots was $395, with another estimated $50 worth used for personal consumption, for a total of $445. The value of broccoli sold was $447. On a per acre basis, the value would be $6764 for beets and $6794 for broccoli. Note that these numbers are net sales totals and do not reflect anything about costs.

Publications/Outreach

Field Day

The furrow guidance system was demonstrated as part of a field day event on June 9, 2015 hosted by the University of Kentucky Cooperative Extension Service, Southern SARE, and Berries on Bryan Station farm at the participating on-farm research farm for this project. The field day event was entitled “Field Day for Market Growers: Mechanization for Organic Vegetable Production.” The furrow guidance system was the main focus of the field demonstrations, although other mechanized systems were also demonstrated including a “Polyplanter” that seeds directly into plastic-covered beds, and an experimental prototype of a driverless tractor being developed by researchers in the Biosystems and Agricultural Engineering Department at the University of Kentucky. (See supporting material for download of field day flyer). Approximately 50 people attended the field day demonstration, based on the attendance roster. (See supporting material for copy of attendance roster). The three-wheeled machine with furrow guidance was demonstrated in several operations during the field day, including planting potatoes, transplanting tomato seedlings, direct seeding beets, and cultivating and hilling an established potato crop. A 15 minute video summary of the field day is available on-line (http://youtu.be/_FoqiAs82aU). Field day attendees were surveyed following the field day. Responses were received from 12 of the field day attendees. (See supporting material for copy of survey results). Survey responses showed strong interest in the furrow guidance system, including several responders indicating willingness to trial the furrow guidance machine on their own farm in the future. Survey responses also included useful suggestions for improvements to the machine, such as incorporating a means to lift the guidance arms without the operator having to leave the seat.

Other Demonstration Activities

The new prototype of the three-wheeled machine using furrow guidance was taken to Rodale Institute’s research farm in Pennsylvania and demonstrated to Jeff Moyer (farm manager) and various staff and farm interns on July 13, 2015. The machine was also
demonstrated at the Virginia Tech University’s Kentland Farm in Blacksburg, Virginia on July 15, 2015. This farm produces organic produce for the university dining service. It was demonstrated to the farm manager, Alex Hessler, several food service personal working on the farm, and to Dr. Ron Morse, retired Horticulture Professor at Virginia Tech who did pioneering work on organic no-till. On July 28, the new prototype was demonstrated during the University of Kentucky’s Horticulture Field Day at the Horticulture Research Farm. The machine was demonstrated to two different groups of approximately 25 people per group.

Posting of Design Plans

A set of design plans for the new prototype of the three-wheeled machine with furrow guidance has been posted on-line on the University of Kentucky Biosystems and Agricultural Engineering Department’s Specialty Crops Mechanization web page (https://www.uky.edu/bae/three-wheeled-machine-furrow-guidance). The design plans include 28 machine drawings accompanied by an extensive narrative with pictures explaining the design and fabrication of the machine. Also included in the posting is a parts list spreadsheet showing sources and costs for materials and parts for the machine. (See supporting material for copies of the design narrative, drawings, and parts list spreadsheet). The posting has been done in an open-source environment. A posting of the machine design plans on the Farm Hack web page is being pursued.

Farmer Adoption

The new prototype of the three wheeled machine with furrow guidance was built for cooperating farmer Erik Walles. The machine was fabricated in the University of Kentucky Biosystems and Agricultural Engineering machine shop, but he paid for all of the materials and he retained ownership of the machine. During the course of the season of work with the machine on Mr. Walles’ farm, it became obvious that it was not well-suited to his operation for a number of reasons. The furrow guidance system works best on fairly flat ground, because of the effect that gravity can have on machine tracking on side slopes. Longer rows are better for efficient operation of the furrow guidance system because of the time lost turning the machine around at the ends of the rows. Wider fields are also better for realizing the benefits from furrow guidance because common furrows can be used for guidance for all adjacent machine passes across the field. However, Mr Walles’ farm is very small (only 7 acres total of property, with only a fraction of that available for vegetable production) and it lacks much flat ground production area. Some areas can be used for fairly long rows but only on the contour, and only in widths of one or two rows. Also, Mr. Walles’ production and marketing situation is not conducive to realizing some of the potential benefits of the
furrow guidance system. Most of his sales are to area restaurants, relying on weekly sales of relatively small amounts spread out over a long season. Many of the potential benefits from the furrow guidance system (such as using the machine as a harvesting aid) can only be realized at a larger scale of production with more concentrated yield.

Despite these shortcomings, Mr. Walles plans to incorporate the use of the machine into his operation in future seasons. Even when offered the chance to sell his machine for the amount of money he had invested in it (by the primary investigator of this project), Mr. Walles declined because he likes how good a job can be done with the machine and how easy it makes certain manual operations. With his scale of production and sales, Mr. Walles cannot afford much hired labor, so he has to do a lot of the vegetable production work by himself. The three wheeled machine with furrow guidance makes certain operations, like planting potatoes or laying drip tape, easier to accomplish with just one person.

In addition to Mr. Walles’ farm, the furrow guidance system is going to be used for vegetable production on one other private farm in 2016, that of the principal investigator of this project. He has secured the loan of the original prototype of the three-wheeled machine with furrow guidance from the Biosystem and Agricultural Engineering Department at the University of Kentucky to use for the production of approximately one acre of vegetables in the summer and fall of 2016. The vegetables will be grown using organic production practices. The system will be used for some crops that have already been tried with the furrow guidance system, including potatoes, beans, and broccoli, and will also be tried on an experimental basis for a number of other crops not necessarily well-suited to the system (vining crops and tall crops).

Several of the respondents to the field day survey expressed an interest in using the furrow guidance machine. However, given the nature of its use, and the requirement that a vegetable production system conform to the way that the machine works, it seems not only unlikely but unwise for a producer to spend the money needed to adopt this technology (probably up to around $10,000 to have a machine and implements for it built) until it is much more field-proven in vegetable production operations. Two of the survey respondents indicated that they would be interested in trialing the furrow guidance machine if funding and support were available, i.e. if they did not have to pay for it to able to try it out, and if someone could help them work with it. A funded project that could build several machines and then support growers using those machines for a couple of seasons of vegetable production seems like the best possibility for getting the technology adopted.
Areas Needing Additional Study

A number of areas need additional study, related both to the design and operation of the machine system and to crop production. There are several important design improvements to pursue, chief among them an electric clutch that would make it much easier to stop and start the machine during operations involving manual work such as transplanting or weeding. An electric clutch would also create the opportunity for remote on/off control such as by umbilical cord or even wireless. Another important improvement from an operational standpoint would be to give the machine a faster “road gear” so that it could be taken to and from the field, or transported between fields, more efficiently. An additional helpful adaptation would be to make it possible to lift the guidance wheels off the ground without the operator having to get off the machine to lift them by hand, for turning at the ends of the rows.

The limitations that the above-mentioned improvements would address directly result from to the overall objective of keeping the design of the machine simple and low cost enough that it could be fabricated in a shop by someone with moderate machinist skills. There are some more fundamental design improvements that may be attainable at a reasonable cost if furrow guidance machines were ever manufactured on a larger scale based on sophisticated engineering design. An electric drive seems ideally suited to the furrow guidance machine system because of the potential for enhanced control of motion (start/stop, speed, etc.). It would also eliminate or significantly reduce noise and exhaust gases (compared to power from an internal combustion engine), an important consideration given the intense nature of the interaction of operator and machine with the system. An electric drive would also create the opportunity for using solar energy to power the machine. Another big improvement would be to have some sort of power take-off capability, probably either hydraulic or electric, for powering rotary implements such as flail mowers or tillers.

There is still a great deal of work to do to refine production systems for specific crops utilizing the furrow guidance machine system. Potatoes seem to be a crop that can benefit greatly from the use of the furrow guidance system because of the ease and labor savings associated with planting and the cultivation capabilities of the system. But the different ways of growing potatoes, as far as using raised beds and/or hilling, in turn affects cultivation operations. Hilling operations with the machine system could be important for other crops not yet tried using the furrow guidance system, such as sweet potatoes, and raised beds could be an issue in fields with poor drainage. For these reasons, more work should be done investigating hilling operations and raised beds with the furrow guidance system. The vines from sweet potatoes and other crops such as winter squashes or watermelons are a limitation for operation of the furrow guidance system. These crops may be well-suited to production using the furrow guidance system otherwise, so work should be done to explore possibilities for training vines to keep guidance furrows open as long as possible, and to investigate weed-control
options and crop responses once the vines have run too much to be able to drive the three wheeled machine over the crop for cultivation.

The furrow guidance concept could also be beneficial for certain applications with crops that are too tall for the current versions of the machine, such as sweet corn, okra, and tomatoes, so design options for higher clearance versions of the machine should be investigated. Finally, efforts should be made to explore possibilities for using the three wheeled machine with furrow guidance for permanent bed systems. Such systems have gained a lot of attention in recent years for intensive organic vegetable production (see The Market Gardener, by Jean-Martine Fortier, and Farming Lean, by Ben Hartman). These systems offer the potential for very high levels of production, but in their current manifestations they require substantial manual labor inputs for intensive applications of compost and mulch and for soil-fracturing operations (using a broad fork). The guidance capabilities of the three wheeled machine, along with the capabilities and adaptability of the three-point hitch lift system, could open up interesting possibilities for significantly reducing manual labor requirements for compost and mulch applications. There may be additional possibilities for machine-powered soil-fracturing operations.

The furrow guidance machine system shows considerable promise for organic production of a wide range of vegetable crops. The capabilities that come from using the three wheeled machine with furrow guidance open up a whole new way of intensively growing vegetables, a hybrid system that combines the benefits of machine power and motion with human capabilities. But the technology is still experimental. Also, it is a technology that requires that the crops be grown in a system built around the machine, rather than the technology/machine being integrated into an existing production system. For these reasons, growers are highly unlikely to spend the money to adopt the technology before it has matured through additional seasons of development work and been field-proven in actual production systems. Yet growers, especially those who are creative and mechanically inclined, are precisely the ones who can best figure out how to improve the technology and put it to beneficial use in organic vegetable production. The best way to accomplish this would be to work cooperatively with a select group of growers, supplying them with a basic machine and associated implements at no cost and supporting their efforts for a couple of seasons using the furrow guidance system to grow vegetable crops. The results from such a project are needed to field-prove the concept and technology to such a point that demand is created for growers to actually spend the money for a machine themselves. That demand can, in turn, create the financial incentive for the kind of commercialization of the technology that could lower manufacturing costs while improving machine operations. At that point, furrow guidance technology would be poised for wider-scale adoption that could substantially benefit market growers of organic vegetables.