Weed Technology 2012 26:382–388

Cultivation Tool Design: Design and Construction of Two Novel Cultivation Tools

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Cultivation tools have a long history of use. The integration of cultivation within current organic and conventional weed management programs is conditional on the availability of functional, practical cultivation tools. However, there are performance and operational limitations with current cultivation tools. Serviceable improvement in weed control is the impetus behind creation of new tool designs. The primary objective of this research was to design and construct two cultivators that might address the limitations of current cultivation tools. A secondary objective was to identify historical influences on the technology, availability, and capability of cultivation tools. Two new tractor-mounted cultivators were designed and constructed as loose extractions of antique handheld tools. The first tool, a block cultivator, has a flat surface in the front of the tool that rests against the soil and limits the entrance of a rear-mounted blade. The second tool resembles a stirrup hoe, where a horizontal steel blade with a beveled front edge slices through the upper layer of the soil. Block and stirrup cultivator units were mounted on a toolbar with a traditional S-tine sweep, so that the novel cultivators could be compared directly with a common standard. Relative to the S-tine sweep, the stirrup cultivator reduced weed survival by about one-third and the block cultivator reduced weed survival by greater than two-thirds. Of the three tools, block cultivator performance was least influenced by environmental and operational variances.

Nomenclature: Block cultivator, cultivation, stirrup cultivator, S-tine sweep.
Key words: Equipment, implement, mechanical weed control.

Las herramientas de cultivo tienen una larga historia de uso. La integración de labores de labranza en programas orgánicos actuales y de manejo convencional de malezas está condicionada a la disponibilidad de herramientas de cultivo funcionales y prácticas. Sin embargo, existen limitaciones de desempeño y operacionales con las herramientas de cultivo actuales. El mejoramiento duradero en el control de malezas es el ímpetu detrás de la creación de nuevos diseños de herramientas. El objetivo principal de esta investigación fue diseñar y construir dos cultivadoras que puedan enfrentar las limitaciones de las actuales herramientas de cultivo. El objetivo secundario fue identificar las influencias históricas en la tecnología, disponibilidad y capacidad de las herramientas. Las dos nuevas cultivadoras para montar en un tractor fueron diseñadas y fabricadas como herramientas similares a las antiguas de uso manual. La primera herramienta, una cultivadora de bloque, tiene una superficie plana en el frente de la herramienta, la cual se apoya contra el suelo y limita la entrada de una cuchilla montada en la parte trasera. La segunda se parece a un azadón de estribo con una cuchilla horizontal de acero que tiene una orilla frontal biselada que rebana la capa superior del suelo. La cultivadora de bloque y de estribo fueron montadas en una barra junto con una cultivadora tradicional, de tal manera que las cultivadoras nuevas pudieran ser comparadas directamente con un estándar común. En relación a la cultivadora tradicional, la cultivadora de estribo redujo la supervivencia de las malezas por cerca de un tercio y la cultivadora de bloque redujo la supervivencia de las malezas por más de dos tercios. De las tres herramientas, el desempeño de la cultivadora de bloque fue el menos influenciado por las variables ambientales y operacionales.

Weed management is a constant agricultural concern. Pulling weeds by hand and hand hoeing were primary weed control techniques for many generations. As sources of farm power shifted, with the integration of horses, tractors, and chemicals, weed management tools and techniques evolved in turn. The design and evolution of cultivation tools has shifted with changes in the sources of farm power.

Modern-day cultivation tools have a limited role within conventional weed management, though there is a resurgent interest in cultivation within organic and reduced-herbicide systems. Limitations with current cultivation tools include high costs, limited efficacy, excessive soil disturbance, and marginal applicability across a range of environmental conditions. The primary objective of this research was to design and construct two unique interrow cultivation tools that might address some of the shortcomings of current cultivators. A related objective was to identify historical shifts in agricultural power, and in society, which have fundamentally influenced the technology, availability, and capability of cultivation tools.

Cultivation Equipment Evolution. Cultivation tools evolved from handheld hoes and early harrows into implements that were pulled behind horses, mules, or oxen. Early cultivators were basic wooden and metal frames with a single forward wheel and tines mounted onto the framework (Blandford 1976). The wheel cultivator, with steel shovels, was invented in 1848 (Gittins 1959). These cultivation units were steered with two outstretched handles. Early models of the straddle row cultivator appeared by 1856 and could cultivate the soil on each side of a single row (Timmons 1970). Most cultivators were shovel types, variations of sharpened pointy-edged blades

DOI: 10.1614/WT-D-11-00023.1
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dragged through the soil. Such cultivator shovels were often little modified from the shovels mounted on field harrows. In the 1890s, American Harrow Co. stated that they had the largest factory in the world. They marketed horse-drawn, walk-behind, one-row cultivators (Wendel 2004).

Production of mechanical agricultural equipment initially centered in Europe. European farmers benefited from the mechanization that occurred during the Industrial Revolution. Designs of some implements were indirectly influenced by machinery advancements in the burgeoning textile industry. For example, cast iron began to be utilized in the construction of gear wheels (John 1973). America was still in a fledgling state, and pioneer farms were using more basic implements than their European counterparts (Blandford 1976). However, once farming became established in the United States, with local sources of equipment, and a rapidly expanding array of manufacturers, machinery development in the United States evolved to the forefront. Machinery shows were popular in Europe in the middle of the 1800s. Machinery trials soon made their way to America, and to this day, these trials offer an important means of disseminating information about agricultural equipment. Farm magazines and papers of the late 1800s, such as the *Prairie Farmer* and the *Wisconsin Agriculturalist*, provided farmers with information about new inventions and gave equipment manufacturers a location to advertise their machines (Johnson 1976).

Farm inventions were not limited to Europe and the United States. For example, creation of the rotovator (rototiller) in 1912 is credited to an Australian engineering apprentice, Arthur C. Howard (Blandford 1976). He made notches in the blades of an ordinary disc harrow so that they formed the still-used L shape. This rototiller was powered by a range of gasoline engines, and found early success in Australia. The rototiller design is still in wide use today.

Johnson (1976) described American farmers as having a love affair with machinery and invention. Those who farmed were engaged in a physical effort, which provided the impetus to develop efficiencies that might speed up operations (e.g., plowing, cultivation, harvesting) or increase the success of a given operation. Farmers needed to improvise, and came up with solutions, adaptations, and improvements to suit their needs. Self-reliance and renaissance abilities facilitated new inventions and modification of old inventions. Johnson (1976) stated that "virtually all the early inventors of farm machinery, later to become agribusiness industrialists, were blacksmiths or wheelwrights." Cultivation tools from different manufacturers were given names like Bellevue and Buckeye, Corn Dodger, New Captain Kidd, Yankee Doodle, and Old Reliable (Wendel 2004).

From the 1850s onward, cultivation tools became increasingly important to equipment manufacturers and farmers alike. Around this time, thousands of patents were granted for cultivator variants and manufacturers were plentiful (Wendel 2004). Many companies were small in size, producing on the order of hundreds of cultivators; several built thousands. The disk interrow cultivator was a natural evolution from the disk harrow (Currie 1916). The spring tooth harrow and rotary hoe first came about as horse-drawn implements (Gittins 1959). Variations in cultivation equipment included walk-behind and ride-along versions, single- and multiple-row configurations, and different shovel types and mounting points.

As an idea for a piece of cultivation equipment became popular, a local blacksmith could often copy the design, or fashion a competing design without issue (Johnson 1976). It was a matter of attrition between inventors and their companies; those without sufficient funds, production capabilities, or talent in distribution and marketing were forced out of business. Small manufacturers were purchased by larger manufacturers, and the field narrowed as competing companies merged or bought each other out. For example, the Emerson Manufacturing Co. was started in 1852. They produced a range of specialty cultivation equipment like the aptly named "No. 1 Beet Cultivator" (Wendel 2004). This company was bought out by J.I. Case Co. in 1928. Then, Massey-Harris Co., Ltd., Toronto, Ontario purchased the Case company in the same year, providing Massey-Harris with a U.S. base from which to operate. In 1880 there were at least 2000 manufacturers of farm implements operating on a combined capital of 60 million dollars (Currie 1916). By 1906, there were approximately 600 farm implement manufacturers remaining.

In the years preceding World War I, agricultural universities were beginning to invest in extension services and experiment stations (Johnson 1976). By 1910, eight state colleges were offering courses in agricultural engineering (Rumeley 1910). Although research and education improved a number of aspects of farm management at this time, there were fewer contributions in the way of mechanical inventions.

The 1930s were a time when smaller, simpler farm machines were being transitioned into larger and more complex pieces of machinery (Johnson 1976). Row-crop tractors began to make an appearance, facilitating development of tractor-driven cultivation equipment (Wendel 2004). Early in 1930, the Oliver Company refined the row crop tractor by placing two small drive wheels in the front of the tractor close together. These closely spaced wheels made it easier to drive the tractor through evenly spaced crop rows accurately (Ganzel 2003). Wendel (2004) notes that farmers were eager to purchase a combination row-crop tractor and cultivator.

Although farm equipment mechanization increased in the 1930s, the onset of the Great Depression made it economically unfeasible for farmers to acquire new equipment (Wendel 2004). Between 1930 and 1932, tractor production dropped from around 200,000 tractors a year to only 19,000 (Ganzel 2003). The number of tractor companies declined as well, from around 90 companies in 1920 to only 9 major manufacturers by 1933. During this time it was simply not possible for growers to purchase new cultivation equipment, or for manufacturers to invest time and money into new tools.

Although small-scale production of horse-drawn cultivators lingered on into the early 1950s, World War II was the separation period during which horse-drawn agriculture was largely phased out and farming became increasingly mechanized. When the war began, the production of farm machinery came to a near halt (Wendel 2004). Only after 1945, when the war had ended, did the production of machinery begin again in earnest. By this time, a number of smaller equipment manufacturers had disappeared.

Following World War II, urbanization and industrialization in the United States swelled. Capable farm workers became harder to find, and, in turn, more expensive to employ. Work in city factories became available. The drudgery of hand weeding and farm tasks could not match the new-found luster of industrialized work (LeBaron et al. 2008). Pressure was mounting for farms to become increasingly mechanized. Weed control by hand, hoe, and cultivator were labors of skill—a concentrated attentiveness was needed to remove weeds growing close to a crop. Carelessness in weeding, mediocre operators, or limitations in equipment capability would result in direct injury to the crop. Weeds that were left uncontrolled would further reduce yields.

Up until around the 1950s, cultivation was the primary weed management strategy in most vegetable crops. However, following the introduction of herbicides in the mid-1940s, mechanical weed control was rapidly replaced or supplemented with chemical weed control. Herbicides placed a new selective pressure on cultivation equipment. When weeds were controlled with herbicides, the crop was not subjected to root disturbance or injury from mechanical cultivation and weed control, particularly in-row weed control, was reliably improved with less manpower and tractor operations (LeBaron et al. 2008).

Cultivation-Tool Diversity. The extent of cultivation-tool diversity has been dependent on changes occurring in agricultural power sources. Handheld implements were designed to work the soil with the limited power of an individual. With the introduction of horses into agriculture, increased amounts of soil could be moved. The subsequent development of steam, gasoline, and diesel-powered tractors provided even more power, and an increasing array of options. With each shift in agricultural power, so too was there a shift in the design, scale, and fabrication of cultivation equipment.

Figure 1 models the relative diversity of hand-, horse-, and tractor-powered tools over time (Blandford 1976; Currie 1916; Ganzel 2003; John 1973; Leichtle 1995; Rumeley 1910). Within the relevant time frame of each cultivation power source there is a point, near to when the power source is most dominant, where tool diversity peaks. This is where there are numerous manufacturers and designs being used by farmers, and where regional preferences and manufacturers are in varied abundance. Thereafter, the cultivation-tool market narrows and there is survival of only those companies who have successfully blended inventiveness, quality of product, fortuity, organization, and business acumen.

Cultivation-tool diversity can be correlated to the relative mobility of farmers and manufacturers. Early hand tools were often made on farm, by local blacksmiths, and by small regional manufacturers. With limited mobility in the 1800s, tool designs evolved to suit the needs of a small local farming base, somewhat independently of tool designs evolving elsewhere. Thus, the time frame during which a diverse range of hand tools existed in the United States was relatively lengthy. By the time on-farm horse usage peaked, and likewise with tractor usage, countrywide interconnectedness and mobility had substantially increased. Farmers now had access

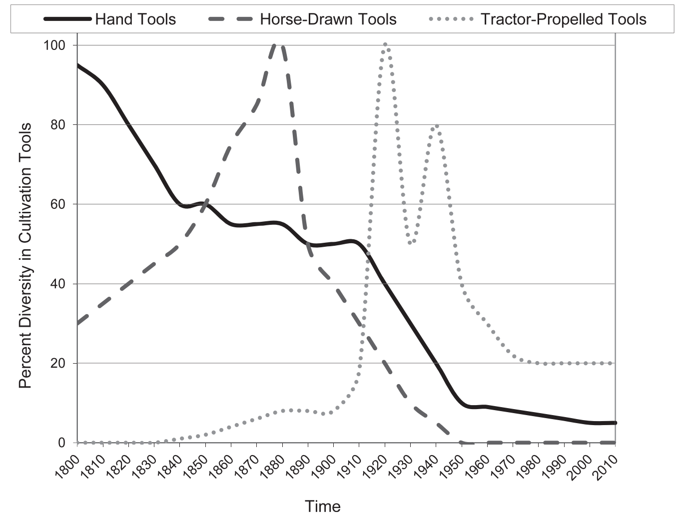

Figure 1. The relative dominance of unique forms of agricultural power over time.

to a wider regional pool of cultivation equipment, large manufacturers were shipping tools across the country, designs were being patented, and farm equipment literature was being widely disseminated. The outcome of increasingly unified agriculture was a decrease in the duration in which a diversity of tools could exist in the market. Once dominant tool companies became established, tool variety narrowed to only these companies' offerings.

Cultivation-tool diversity was also directly influenced by major developments in society at large. The Great Depression brought development of new farm equipment to a virtual halt. World War II signaled a shift from agricultural machinery production to wartime production efforts. Both of these events decreased the diversity in available farm equipment (Figure 1).

A facilitating factor in early cultivation tool diversity was the number of farmers. In the years preceding 1850, at least 65% of the population lived on farms, where seasonal removal of weeds was a primary duty (Gianessi and Reigner 2007). By 1910, there were over 6 million farmers in the United States and almost 40% of the population lived on farms (Currie 1916). Thus, during these years there were a large number of potential customers, each with different ideas on what types of cultivation tools would be the best investment. Likewise, there were a large number of tool-producing companies trying to fill these on-farm needs.

Over time, the numbers of farmers and farms have decreased. By 2005, there were approximately 2 million operating farms and less than two percent of the population lived or worked on-farm (U.S. Department of Agriculture [USDA] 2009). The current reliance on chemical weed control further decreases farm demand for cultivation equipment. The decline in the number of farmers, and the specialization of farms, currently limits the market's ability to support production of a diverse array of cultivation tools.

At present, the majority of farm equipment is built and sold by large businesses. Product development costs, and the complexity of materials and of the product itself, restrict the small-scale inventor and manufacturer. Although there are a variety of different cultivation tools on the market, most cultivation implements we have today have not been greatly changed in over 100 years (Bowman 1997). However, small European companies now lead the way in new tool advancements with companies and equipment, including Bärtschi-FOBRO's brush hoe (Switzerland), Kress and Companies' Finger Weeder (Germany), and the CMN Companies' Couch Grass Killer (Denmark).

The history of cultivation tools has been directly related to the evolution in power sources on the farm. New tool invention has consistently been spurred by a desire to harness the capability of new power sources. Despite thousands of variants in cultivator designs appearing over the last few centuries, only a limited number have made it to the present day. Revived interest in cultivation tools hinges on their potential resurgence in organic agriculture and in alternative systems that restrict the use of conventional herbicides or promote the integrated use of cultivation. Demonstrated viability of guided-cultivation systems, robotic cultivators, and novel tool designs may help spur a renaissance in cultivation on the farm.

Design and Construction of Novel Cultivation Tools

Designs for two new tractor-mounted cultivators were loosely extracted from patents of antique handheld tools (Morgan 1903; Oakland 1928). These new cultivators were drafted with the aid of engineering software (AutoCAD, Autodesk Inc., 111 McInnis Parkway, San Rafael, CA 94903) and constructed in the Metal Technologies Working Lab at Cornell University. Costs of materials and time of construction were documented. The tools were designed specifically for mounting on a standard toolbar; this toolbar could then be attached to any tractor equipped with a three-point hitch.

The Block Cultivator. One impetus behind the design of the first tool, called a block cultivator, was a design for a handheld tool patented in 1928 by M. Oakland (Figure 2). There are no current cultivation tools that resemble or function identically to the block cultivator. Views of the implement are shown in Figure 2. As the tool is pulled across the soil, a blade cuts in and lifts soil onto and over its wide, inclined surface. A flat block in the front of the tool rests against the soil surface. A rear surface behind the blade also rests against the soil. These two surfaces apply critical pressure on the soil while limiting penetration depth of the cutting blade.

A contributing model in the design of the block cultivator was a woodworker's block plane. With a block plane, a flat sole (base) regulates the depth of a mid-mounted cutting blade, facilitates evening out of uneven surfaces, and provides down pressure against the wood (Noyes 1910). Likewise, with the block cultivator, the flat blocking to the front and rear of the blade smooths the soil surface and allows the tool and toolbar weight to rest heavily against the soil without excessive blade penetration.

Mechanisms for tool adjustment were built into the prototype to allow for configuration flexibility. The blade depth can be adjusted from 1.3 to 5.1 cm. The forward block can be adjusted from a horizontal position to an upward angle, to minimize soil buildup at the front of the tool. To each side of the front surface are 1.3-cm-thick extensions that project 1.3 cm below the cultivator frame. These extensions aid in cutting the soil surface on each side of the cultivator, prior to the blade entering the soil area between each protrusion. All testing was conducted with the blade at the shallowest setting (1.3-cm depth, 20° blade angle) and the forward block angled upward in the front.

The tool was designed for durability and use in potentially stony soils. The frame of the tool was constructed of 1.3-cm mild flat steel. The 1.3-cm-thick blade was beveled to 45 degrees on the upper edge. Hard surfacing was added to the lower side of the leading edge to reduce blade wear. Twenty centimeters were left open between the rear edge of the front surface and the leading edge of the blade to allow soil-surface rocks of less than 20-cm diameter to pass through. Angled arms on each side of the cultivator frame extend upward to a central plate, from which a 1.9 by 5.1–cm hardened steel shank extends upward into a standard, premanufactured toolbar clamp (Bigham Brothers Tool Bar Shank Clamp [806-402], Bigham Brothers, Inc., 705 East Slaton Road, Lubbock, TX 79452).

This cultivator could be dimensionally altered to work within different row crop spacings. In its current form, two block cultivators are used in tandem for cultivation of a single interrow space. Adjustment of tool position on the toolbar of one or both cultivator units allows for cultivation of a wide range of interrow widths. The current design utilizes a single pivot point for adjustment of the rear-mounted blade. This means that as the depth of the blade increases, so does the blade angle. An alternate version should incorporate a means of depth adjustment that would not also change the blade angle.

The Stirrup Cultivator. The second tool, called a stirrup cultivator, is similar in appearance to a stirrup hoe, where a horizontal steel blade slices through the upper crust of the soil (Figure 3). The impetus for creation of this design came from an illustration of a handheld tool patented in 1903 by E. B. Morgan (Figure 3). Structurally, the stirrup cultivator is distinct from current cultivation devices. This tool, like the block cultivator, was designed specifically for mounting on a standard toolbar. The tool incorporates a horizontal steel blade, with an angled front and rear edge, to slice through the upper crust of the soil. The blade is approximately 33 cm long on the horizontal portion, 7.6 cm wide, and 1.3 cm thick. The wide span of the tool permits large rocks to pass through. The thickness of the blade forces soil to move up, over, and down the course of the blade. This movement contributes to increased soil aggregate separation relative to a thinner, flatter blade. The front and rear of the blade's upper surface are beveled to 45 degrees. This bevel extends upward on each side of the blade as it curves to meet the angled arms to which it is attached. This bevel facilitates cutting into the soil.

The tool was constructed to be strong and flexible. A layer of hard surfacing was added to the bottom of the leading blade edge to slow wear. The blade was also designed to be reversible, to increase service life. Two 1.3-cm-thick arms bolt to the blade, one on each side, and these arms angle upward

Figure 2. The block cultivator. Clockwise from top: original illustration of a hand tool designed in 1928 by M. Oakland; top-down view with the front of the cultivator to the right; rear view of soil disturbance after cultivation; side view showing the tool shank extending upward into a toolbar clamp and the toolbar attached to a tractor via a three-point hitch; side view of block cultivator with the front of tool to the left.

Figure 3. The stirrup cultivator. Clockwise from top: original illustration of a hand tool designed in 1903 by E. B. Morgan; front and side view; soil disturbance after cultivation; rear view of the cultivator where the tool shank extends upward into a toolbar clamp; top-down view.

https://doi.org/10.1614/WT-D-11-00023.1 Published online by Cambridge University Press

into a 1.9-cm-thick central plate. From this plate, a hardened steel shank extends upward, and into, a standard toolbar mounting clamp (Bigham Brothers). Holes in the central plate allow the tool to be held in a horizontal position or angled to the front or rear. Tool depth is regulated by the tractor operator through raising or lowering the three-point hitch, or by raising or lowering the shank height within the toolbar-mounted clamp. In testing, the tool was held in a fixed horizontal position and depth was restricted to between 2 and 8 cm.

Field Trials

Trials were conducted in 2008 to assess the weed control potential of the block and stirrup cultivators relative to a standard S-tine sweep cultivator. Additional trials were carried out in 2009 to assess crop response to each of the aforementioned tools. A full report on this research is forthcoming in *Weed Technology* (Evans et al. 2012). Relative to the S-tine sweep, the stirrup cultivator reduced weed survival by about one-third and the block cultivator reduced weed survival by greater than two-thirds. Crop response to each cultivator was identical. At the time of this writing, Cornell University holds license rights to the stirrup and block designs.

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Received February 28, 2011, and approved January 12, 2012.