Review Article

Inter and intra row weeder: A review

ABSTRACT

One of the most important agriculture operation is to properly manage weeds. Weed management is a tedious task. If weeds not properly manage, it's bad effect reduced crop yield as well as quality and increases in harvest cost. Weed management often requires major resource inputs to produce a successful crop. Two types of mechanical weed control methods, inter-row and intra-row mechanical weeding, are reviewed and discussed. Specifically, the most commonly used manual inter-row mechanical weeding tools are reviewed and compared according to their working principles. The more challenging area of intra-row mechanical weeding is reviewed, and manually operated intra-row mechanical weed control tools are compared. The current state of the art in automated mechanical weeding is discussed along with some cuttingedge technologies for intra-row mechanical weed control found in industry and the research community.

Highlights

- Most mechanical weeders has weeding efficiency in range from 60 to 80 %.
- That operate at depths and forward speed ranging from 1 to 2 cm (0.39-.78 inch), and 0.7–9.7 kmph (0.43-6.0 miles/h.
- The additional innovative vision-based weeders require slow forward speeds with a larger plant spacing to ensure good weed control.
- Automation is a natural next step for this concept since it has great potential to improve weed control efficacy and minimize to desire plant damage.

Keywords: *weed, weed effect, weed loss, weeder, inter weedr, intra weeder*

01 INTRODUCTION

In India, weeds are one of the major biological constraints that limit crop productivity. A weed can be thought of as any plant growing in the wrong place at the wrong time and doing more harm than good (Parish, 1990). Weeds have very fast growth rates compared to crops, and if not preserved and managed, they may control the field. This sustainable nature will unfortunately affect the crop yield (Slaughter *et al.* 2008). Gianessi and Sankula (2003) reported that most crops require that the field be kept weed-free during the first 4–6 weeks after planting to prevent serious yield losses from early season weed competition. One of the most important agriculture operation is to properly manage weeds. Weeds affect crop yield due to competition to acquire plant nutrients and resources (Slaughter et al. 2008; Weide *et al.* 2008).Weeds reduce the productivity, increase the cost of cleaning and overall adversely affect the value of the land and thereby affecting the farmer's energy, time or money (Parish, 1990). A crucial operation in farm management is the control of weeds, mainly due to its negative effects on crop yield and quality. Weed control methods are generally categorized as mechanical, biological, cultural, chemical, and preventative. Conservative farming greatly depends on herbicides, whereas organic farming depends on relations between preventive methods and mechanical weed control. There are many types of commercial mechanical weeders that use the three main physical techniques for controlling weeds: Burying, Cutting, Uprooting.

02 RESULTS AND DISCUSSION

Weeding is one of the important, crucial and difficult operations which affect both on productivity and profitability of rain fed agriculture that accounts for a major share in cost of agricultural production, If not controlled properly. More than 33 % of the cost incurred in cultivation is diverted to weeding operations there by reducing the profit share of farmers (Chavan *et al*., 2015).

Crop and weed populations are often not uniform in the field. Weeds may occur in patches of varying size, densities and growth stages; some areas may have few or even no weeds within a weedy field. Also soil characteristics such as soil texture, soil moisture content and organic matter may vary significantly within a field. Therefore, there is need to vary of mechanical weed control according to the variations in the field. The objectives of weed management are to identify the variability, and to analyses and manage weeds according to their spatial and temporal variability (Blackshaw *et al*. 2007).

Harrows and rotary hoes are weeding of whole crop that's why chances of crop damage. However, mechanical weeding may also support to crop growth due to soil loosening, reduction of evaporation, soil aeration and induction of mineralization *(Steinmann 2002).* The challenge is to succeed a high degree of weed control without unacceptable crop damage. Spring tine harrows, also called flexible tine harrows, are the most employed implements for whole crop cultivation, but other types of harrows like the chain harrow, are also used. But rotary hoes are commonly used initial or in very early growth stages (Place *et al*. 2009).

Weeding operation may perform in the crop row (intra-row weeding), strips between crop rows (inter-row weeding) or the full surface (whole crop weeding) (Vanhala *et al.* 2004), and it is mostly carried out with harrows, hoes and brushes (Dierauer and Stoppler-Zimmer 1994, Pallutt 2002). Inter-row and intra-row weeding need precision in terms of steering. The highest precision is mandatory for intra-row weeders. But also inter-row weeders that operate close to the crop rows want precision. In practice, it is possible to leave about 10 cm wide uncultivated strips around the crop row if steering is highly accurate (Gupta *et al*. 2008). Most inter-row device are carried out in row crops with rows spaced 50–90 cm apart. Inter-row operation, is possible in cereals and other crops normally reputable in narrow-row systems. Row spacing of about 20 cm is considered as a minimum to allowable for inter row weeding.

The weed control mechanism of harrowing is mainly by soil burying (crop soil cover), but also uprooting plays a role when weeds are small, (Kurstjens and Kropff 2001).

The mostly weed control devices are designed for use between crop rows (inter-row) (Cloutier *et al.* 2007). There are only a rare machines that are designed for use in the intra-row of crops.

2.2 Mechanical Inter-row Weeder

Mechanical inter-row weeding is mostly used by farmers in place of herbicides. It is used in row crops like cereal crop, sugar beets and vegetables, etc.The objective of inter-row weeder is to weeding as greatly of the inter-row area as possible without damaging the crop.

Weed control can only be done during the initial crop stages because limited tractor and substitute ground clearance and machine-plant contact may potentially damage the crop vegetation at later growth stages (Cloutier *et al.* 2007). So, these limitations, there is a wide selection of weeder implements that can be used for mechanical inter-row weeding.

Inter-row weeder are the most common machine used for mechanical weed control. This agriculture implement consists of cultivating tools mounted on a toolbar that either rotate or sweep to move soil, bury, cut, or uproot the weeds.

Most inter-row weeder have sweeps, weed knives or shovels working in a depth of 2–4 cm. The ordinary hoe blades (e.g. duck foot) are mounted on rigid or vibrating shanks. Usually, three to five shanks constitute a gang that is mounted on a toolbar, and each gang cultivator an inter-row spacing. An inter-row cultivation may also be carried out with rolling cultivators and PTO-driven cultivators (Melander 2006).

The sweeping-type weeder use triangular-shaped or duck foot-shaped blades that are swept under the soil but near the soil surface. The blades vary in width, from as small as 5.1 cm (2 in.) to as large as 71.1 cm (28 in.).

This type of weeder does not require any power that provided through the draft force from the tractor. Recommended travel speeds for sweeping- type cultivators are 4–7 mile/h. (6.4-11.26 kmph). Different Agricultural Residues and Their Bio-Char Characteristics (Makavana et. al 2021).

Another type of weeder is rotating type such as rotary tilling and rotary tiller, which are commonly used for inter-row weed control. However, the latter machine is more expensive, since it has been designed for multiple functions, such as strip planting into cover crops and preparing permanent plant beds. These rotary tilling implements use separately postponed inter-row gangs or blades, which are mounted on circular discs with parallel linkages. The cutting blades or knives vary in width, from 5–60 in (CM MA KARAVUUUUU). Metal housings can be used to cover the tilling blades to avoid crop damage. Recommended forward speeds are 2.5–5 mile/h (4-8 kmph) (Bowman 1997).

The basket weeder is an implement that consists of rolling rectangular-shaped quarterinch spring wire forming a round basket (Fig.1). This basket weeder is ground driven, similar to the sweeping-type cultivators. The basket weeder will remove weeds at the top surface of the soil, without moving soil into the crop row. This machine is suitable in moist soils in minimal clay content. It performs weed control at forward speeds of 6.4 km/h (4 mile/h) to 12.9 km/h (8 mile/h) (Bowman 1997).

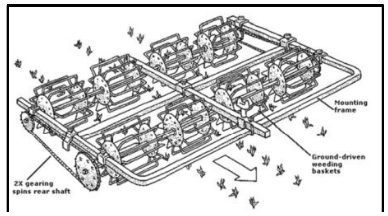

Fig. 1: Basket weeder for inter-row weed control (Bowman 1997)

As for harrowing, success of hoeing depends on arid climate conditions of soil. It can be used rather in late growth stages and timing is not crucial (Melander *et al*. 2005). If the hoe is too severely operated on rooted weeds, may grow again when sufficient moisture is available in the soil. In a place of cutting blades, horizontal rotating brushes are used for special soil conditions. The weeds are brushed by rotation of hard polypropylene fibers and the control mechanisms are mainly by burial with soil and uprooting of weeds so they stay exposed to desiccation, stripping leafs and breaking stems (Melander 1997). Manual guidance or autonomous guidance system of the brushes between the rows is indispensable.

The first inter-row brush was developed in 1985 to be used in cereals with 17 cm row distance (Dierauer and Stoppler-Zimmer 1994). For ideal weed control, the inter-row distance must be at least 17 cm. The main advantage of the brush weeders is that they can efficiently be operated on upper soil moisture conditions than for harrows or hoes. The risk of using brushes is that soil structure is destroyed and the soil becomes very sensitive for compaction after rainfall.

Hoes are used in row-crops as well as cereals as an addition to whole crop. For instance in cereals, the effect of weed harrowing is often poor in heavy soils and a combination of inter-row hoeing and whole crop harrowing may improve weed management (Rasmussen and Svenningsen, 1995). Thus, an additional pass with the hoe might be extra effective to control sticky weeds such as Galeopsis tetrahit, Galium aparine, Matricaria chamomilla and Vicia hirsuta (Dierauer and Stoppler-Zimmer 1994). The crop row to raw distance must not be < 20 cm (Melander 2006). Two passes with the hoe in maize and peas (Pisum sativum) may reduce inter-row weed density by 90% and intra-row density by 75% (Dierauer and Stoppler-Zimmer 1994). An accurate steering of the hoe is required, since its shares undercut everything when being pulled. Therefore precise seeding of the rows eases the guidance of the hoe between the rows (Griepentrog *et al.* 2006). Generally manual steering is used as a most common guidance method to command the hoeing implements for reduce crop damage.

Some automatic guided hoeing systems based on computer vision technology have been introduced. These systems goal to reduce the attention needed by the tractor driver (Melander *et al.* 2005).

2.3 Mechanical Intra-row Weeder

Mechanical intra-row weeders control weeds within the crop rows. There exist a number of implements for intra-row weeding. Most are low-tech and they are simply pulled along the rows. Their performance is highly dependent on crop-weed selectivity factor.

These types of implements accomplish their goal using two different methods depending on the crop density. The first method is to use selective machines or add-on tools that can execute weed control close to the crop, without damaging the crop itself. This method does not require any sideways movement of the weeder. The second method is to use machines that have weeding tools that move sideways to conduct weed control around the crop canopy.

Below are some of the machines that have been reported to be effective in weed control. Among the most common low-tech implements are finger weeders and torsion weeders, (Weide *et al.* 2008).

2.3.1 Finger Weeder

The finger weeder is a simple mechanical intra-row weeder. That uses two sets of steel cone wheels to which rubber spikes or "fingers" are a fixed. The fingers point horizontally outward at a certain angle and operate from the side and beneath the crop row with ground-driven rotary motion (Fig.2). The rubber fingers penetrate the soil just below the surface to remove small weeds. The finger mechanism performs best in loose soil and poorly in heavily crusted, compacted soils or where heavy residue is present. This type of weeder is effective against young weed seedlings up to 2.54 cm (1 in.) tall and interacts easily with well-rooted crops. The recommended operating depth is 12.7 mm (0.5 in.) to 19.1 mm (0.75 in.). The recommended forward speed to use with this weeder is 4.8 km/h to 9.7 km/h (3–6 mile/h). Alexandrou (2004) reported the finger weeder and obtained weed efficacy results of 61 % of the intra-row weeds killed in organic corn. A disadvantage, is that the tractor must be steered very accurately so that the finger mechanism can work as close as possible to the crop rows (Bowman 1997; Cloutier *et al.* 2007; Weide *et al.* 2008).

Fig 2: Finger weeder uses rubber spikes that are pointed at an angle towards the crop (Weide *et al.* 2008)

2.3.2 Torsion Weeder

Torsion weeders use an inflexible frame that has spring tines connected and bent. So that two short tine sections are parallel to the soil surface and meet near the crop plant row. This arrangement permits crop plants to pass through the tine pairs. The coiled spring tines permit the tips to flex with soil contours and around established crops. These weeders have been displayed to reduce weed densities to 60–80 %. Torsion weeders need very precise steering with relatively low forward velocities and hence have a low working capacity. Exact steering is required to avoid damaging the crop, since the tines operate very close to the crop. Torsion weeders are frequently used together with precision cultivators to perform effective weeding (Bowman 1997; Cloutier *et al.* 2007; Weide *et al.* 2008).

3.3.3 Brush Weeders

Melander (1997), they are designed with vertical brushes that are powered by hydraulic motors. Brush weeders uses flexible brushes made of fiberglass or nylon and rotated about vertical or horizontal axes. The brushes can be assembled at any desired width and spacing based on the crop. The working depth is about 2.0–3.0 cm. These weeders mainly uproot but also bury and break weeds.

A protective cover can be installed to keep the crop from being damaged. An operator is required to steer the brushes to cultivate as close and as many weeds as possible without damaging the crop plants (Melander 1997; Cloutier et al. 2007).

Fogelberg and Gustavsson (1999) studied the use of a brush weeder as an intra-row weed control in carrots and reported that the brush weeder was effective at initial weed growth stages, specifically in the 2–4 true leaf stages. Weeds were uprooted 45 to 90 % using a working depth of 0.6 in. They concluded that the key mechanism of weed control found by brush weeding was uprooting, because brush weeding applies a greater uprooting force compared to the root anchorage force for the weed plants.

Kouwenhoven (1997) is stated on research investigating a brush weeder for intra-row weed control. In an experiment conducted in maize and sugar beet crops. It was determined that the best rotational speed for the brush weeders was 240– 360 rpm with a forward travel speed of 1.2 mile/h (1.9 kmph). Results showed that brush weeding for maize was more effective than hand weeding. So, sugar beet plant damage was reported due to steering inaccuracy and fine soil created by the brushing effect. Combining this together with the humid weather conditions, it resulted in additional weed plant appearance after the weeding operation.

3.3.4 ECO-Weeder

The ECO-weeder is an intra-row weeder that is three-point hitch mounted on tractor. It is driven by the power takeoff (PTO) of the tractor to drive a belt system that powers two discs with tines (Fig.3).

Fig.3: ECO weeder requires an operator to move rotating weeding mechanisms with tines (HCC. 2011)

This machine is similar to the brush weeder described above, but uses a mechanical drive and does not require any hydraulic power. It is a good option for small production-scale vegetable growers because of its low price and low maintenance costs. The minimum tractor size wanted to power the ECO-weeder is 14.7 kW (20 hp), and the PTO speed required is 540 rpm. It still requires an operator to move two rotating discs with vertically oriented tines in and out of the crop row. The forward speeds used by farmers are between 0.5–1.5 mile/h (0.80-2.4 kmph), and the rotation speed of the weeding element is estimated to be 150–300 rpm, similar to that of the brush weeder as reported by Kouwenhoven (1997). It was reported by the manufacturer that the ECO-weeder can save up to 60 % of weeding costs when compared to manual weeding due to the reduced labor requirements: two workers instead of eight workers (Univerco 2011). The weed control efficacy has not yet been reported.

3.3.5 Cycloid Hoe Weeder

The cycloid hoe is a high-tech device for intra-row weeder. (Kielhorn *et al*. 2000). A cylindrical rotor works as an actuator and holds eight tines placed around a vertical axis. The tines rotate in a circular motion, at a rotational diameter of 0.234 m (Griepentrog *et al.* 2006) (Fig.1.). This translation movement of the rotor together with the forward straight-line movement of the implement generates a cycloid. Every single tine can be in and out folded by an electromagnetic circuit to avoid crop plants, once the sensors have recognized them. The forward speed of the vehicle is 8.5 kmph (5.28 mile/h). The cycloid hoe has been further developed, tested and problems have been reported such as high crop damage and low control efficacy (Griepentrog *et al.* 2007).

Griepentrog *et al.* (2006) developed and reported an autonomous intra-row weeder based on RTK (Real-Time Kinematics) GPS to locate the weeder relative to crop seed maps. This weeder used a rotary weeding mechanism. That is rotated using an electro-hydraulic motor. The mechanism consisted of eight tines with tine tips having an outer diameter of 23.46 cm (0.77 ft.). These tines can be controlled individually to follow two different tine trajectories. Dyer *et al.* (2012) designed a rotary intra-row hoe in grouping with real time sensors for robotic weeding, which is expected to be fast and effective in weed control.

3.3.6 Bezzerides Weeder

Schweizer *et al.* (1992) reported selective weed control through post-planting bezzerides in-row weeder as an attempt to site-specifically manage weeds. The in-row cultivator has tools that move the soil away from the rows and later into rows, thus uprooting and burying in-row weeds. Rotary hoes at the first gang of the implement move soil away from the crop row in the first cultivation and into the row on the second cultivation, covering small weeds. The following gangs are composed by torsion weeders, spinners (rotary harrows), and spring hoe weeders. The torsion weeders and rotary harrows were used during the first pass; the torsion weeders and spring hoes (which replaced the spinners after the first cultivation) were used for the second and third passes. Brush weeders also exist for intra-row weeding.

3.4 Automated Technology in Weeding Operation

Automation technology has been applied to weed control that has resulted in a grouping of manual and machine approaches. By using automation, a machine offers the possibility to determine and differentiate the crop plants from weed plants and, at the same time, remove the weed plants with an accurately controlled device (Bakker 2009). Slaughter *et al.* (2008) in a review on autonomous robotic weed control systems identified four basic technologies desirable for automated weed control: (a) Guidance, (b) Detection and identification, (c) Precision in- row weed control, (d) Mapping. The machine had a multi-sensor system for plant recognition composed by three sensors: Height-profile sensor, Area allocation sensor and Soil-plant sensor

Based on that, described several intra-row weed removal mechanisms for robotic technology. The mechanical-based designs was using mechanical knives that can rapidly position in and out of the crop row. Row guidance systems can use machine vision for crop row detection and as well as global positioning systems (GPS). Machine vision has the capability to recognize crop rows at travel speeds ranging from 1.6–6.2 mile/h (KMPH) and produces very minor errors in identification, ranging from 4.7–10.6 mile/h (7.56-17 kmph). So, GPS has the ability to deliver a lateral positioning accuracy along the row with RMS error of 2.4 in and the extreme error distance of 13 cm (Slaughter *et al.* 2008). However, row guidance systems require that (1) The crop be planted using Real-Time Kinematics (RTK) GPS-guided planting system,(2) The crop rows be mapped using some type of geo-referenced mapping technique.

Recognition and identification of weeds and the crop is very challenging to perform in real time. Weed identification techniques rely on machine vision systems and image processing techniques. That's are depends on biological morphology, spectral characteristics, and visual structure. Steward and Tian (2005) used environmentally adaptive segmentation algorithm (EASA) to develop real-time machine vision weed detection for outdoor lighting conditions. Tang *et al*. (2000) used colour image division using a binary-coded genetic algorithm (GA) for outdoor field weed identification under different lighting situations. Precision intra-row weed control can use mechanical, chemical, thermal, or electrical, etc approaches. Mechanically automated weed control such as the automated thinners uses mechanical knives that travel in and out of the crop row or use a rotating hoe that could be height adjusted (Astrand and Baerveldt 2002). Development and performance evaluation of batch type biomass pyrolyser for agricultural residue (Makavana et. al 2020).

3.3.8 Automated Mechanical Weeders

Tillett *et al.* (2008) tested and reported a weeding machine using computer vision to sense plants. This automated intra-row weeder used a rotating half circle disc. That rotated to avoid contacting the crop plants during weeding. A camera was mounted centrally on the implement at a height of 170 cm (5.6 ft.) looking ahead and down such that the bottom of the field of view was vertically below the camera, and the full width of the bed was visible over a length of approximately (8.2 ft.) (cm). the position of the plants along the crop row and their location relative to the rotating disc were detected using computer vision. An experiment on a cabbage plot was conducted using an intra-row crop plant spacing of 30.48 cm (1 ft.) And a forward speed is 1.8 km/h (1.73 mile/h). Weeding treatments were conducted at 16, 23, and 33 days after transplanting (DAP). The greatest results were found at 16 and 23 DAP, with 77 and 87 % decrease in the number of weed plants, respectively. So, after 2 weeks of following weed regrowth and new germination, the number of weed plants after the 16 DAP weeding treatment was still reduced by 74 %, while a number of weed plants after the 23 DAP treatment were still reduced by 66 %. Under the experimental circumstances, it was shown that performing weed control at an initial stage succeeded in controlling later weed regrowth and new germination. This machine was commercialized under the name Robo-crop (Inman 2010).

Astrand and Baerveldt (2002) developed an agricultural mobile robot with vision-based for weed detection and succeeding control. This machine required two cameras. One grayscale camera with a near-infrared filter to obtain high-contrast images. That located at the front to identify the crop row location and direction. Another, a colour camera to identify crop plants, located at the center of the machine, facing downward toward the soil.

A weeding tool, which was a rotating wheel oriented perpendicular to the crop row, was located at the rear of the machine. The tool was lowered using a pneumatic cylinder when gap between crop plants was sensed and provided some tilling act in the intercrop plant area. At a speed of (0.66 ft/s) (0.72 kmph), the weeding robot presented good perception performance. The crop row detection camera was able to identify crop rows based on a row-recognition algorithm with a (0.8 in.) (2.0 cm) error. The crop finding color camera successfully, detected crops using image division systems to categorize weeds and crops using color and shape features. But, they are, the weed control efficacy of the machine was not reported.

The research focused more on the perception system for crop as well as crop row detection, but not on weed control in specific. Cloutier *et al.* (2007) reported on the Inter-row hoe automated weeder sensed reflected light from the field surface to sense crop plants. They used a system to control the motion of a hoe around the crop plants. It was mainly developed for transplanted crops. That is best operated when the weeds are significantly smaller than the crop plants. The working speed of the prototype was reported to be (1.9 mile/h) (3.0 kmph). FG (2008) stated that the Dutch Applied Plant Research organization is continuing to develop this prototype, hoping to achieve an operating speed of (2.5–3.7 miles/h) (4.0-5.95 kmph) and to effectively control higher population weeds between the crops.

03 CONCLUSION

Currently, most mechanical weeders has weeding efficiency in range from 60 to 80 %. That operate at depths and forward speed ranging from 1 to 2 cm (0.39-.78 inch), and 0.7–9.7 kmph (0.43-6.0 miles/h) respectively. Automated weeding machines have not used electrical power for the weeding mechanism. But, mechanical as well as fluid power has been mostly used for controlling the weeding actuators. By using electric and electronics, it is hypothesized that more precise control of the weeding actuators can be accomplished. Also, the power consumption of the system can be supervised to recognize the effect of soil depth, actuator speed, and other factors on required power. Electrical systems do not leak and cause soil contamination like hydraulics systems which is also prone to hydraulic fluid leakage. Although the performance of current non-automated mechanical weeding technology seems promising, there are some other issues that should be considered. Machines such as the finger weeder and the torsion weeder require accurate steering to minimize crop damage. Brush weeders, although they have good performance, require an operator or operators at the rear to move the brushes in and out of the crop row. The additional innovative vision-based weeders require slow forward speeds with a larger plant spacing to ensure good weed control. Automation is a natural next step for this concept since it has great potential to improve weed control efficacy and minimize to desire plant damage.

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