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Inter and Intra Row Weeders: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

One of the most important agriculture operations is to properly manage weeds. Weed management is a tedious task. If weeds aren't effectively controlled, it will negatively affect crop output, quality, and harvest costs. To grow a successful crop, weed management frequently requires significant resource inputs. Review and discussion of inter-row and intra-row mechanical weeding, two different mechanical weed control techniques. In particular, reviews and comparisons of the most popular manual inter-row mechanical weeding tools are made in accordance with their functional principles. The more challenging area of intra-row mechanical weeding is reviewed, and manually operated intra-row mechanical weed control tools are compared. Along with various cutting edge solutions for intra-row mechanical weed control discovered in industry and the research community, the state of the art in automated mechanical weeding is being explored.

Highlights:

- The majority of mechanical weeders have weeding efficiency between 60 and 80 percent.

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- That functions at forward speeds ranging from 0.7-9.7 kmph (0.43-6.0 miles/hour) and depths between 1 and 2 cm (0.39 and.78 inch).
- Automation is a natural next step for this concept since it has great potential to improve weed control efficacy and minimize to desire the plant damage.

Keywords: Weed; weed effect; weed loss; weeder; inter weeder; intra weeder.

1. 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" [1]. Weeds grow far more quickly than crops do, and if they are not controlled and maintained, they may take over the entire field. Unfortunately, its sustainable nature will reduce crop productivity [2]. Gianessi and Sankula [3] 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". Managing weeds effectively is one of the most crucial agricultural tasks. Weeds reduce crop productivity because they compete with plants for resources and nutrients [2], (Weide et al. 2008). "Weeds reduce 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" [1]. Weed control is an essential aspect of farm management, primarily because it has a detrimental impact on crop productivity and quality. There are several different types of weed control techniques, including mechanical, biological, cultural, chemical, and preventative. Organic farming relies on the interactions between preventive measures and mechanical weed control while conventional farming heavily relies on herbicides. There are various commercial mechanical weeders that employ the three physical weed management methods of Burying, Cutting, and Uprooting.

2. LITERATURE REVIEW

Weeding is one of the significant, critical, and challenging tasks that, if improperly managed, can have a negative impact on rainfed agriculture's productivity and profitability and contribute significantly to the cost of agricultural production. More than 33 percent of the costs associated with cultivation are redirected to weeding activities, which lowers the farmers' profit margin [4].

"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" [5]. As a result, mechanical weed management needs to be adjusted in accordance with changes in the field. The goals of weed management are to recognise variability, assess it, and treat weeds in accordance with its temporal and spatial variability [5].

Harrows and rotary hoes are weeding of the 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 [6]. The difficulty is achieving a high level of weed management without unacceptably damaging crops. The most common harrows used for whole crop cultivation are spring tine harrows, also known as flexible tine harrows, although other harrow types, like as the chain harrow, are sometimes employed. However, rotary hoes are frequently employed in the earliest or very early growth stages [7].

"The 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)" [8], and it is mostly carried out with harrows, hoes and brushes [9,10]. "Inter-row and intra-row weeding need precision in terms of the 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" [11]. Most inter-row devices are carried out in row crops with rows spaced 50–90 cm apart. The 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" [12].

The mostly weed control devices are designed for use between crop rows (inter-row) [13]. There are only rare machines that are designed for use in the intra-row of crops.

2.1 Mechanical Inter-row Weeder

Farmers typically substitute mechanical interrow weeding for herbicides. Row crops including vegetables, sugar beets, and cereal crops, among others, use it. An inter-row weeder's goal is to weed as much of the inter-row space as they can without harming 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” [13]. So, with these limitations, there is a wide selection of weeder implements that can be used for mechanical inter-row weeding.

The most typical device used for mechanical weed control is an inter-row weeder. To move dirt, bury, chop, or remove weeds, this agricultural instrument consists of cultivation tools mounted on a toolbar that either rotates or sweeps.

The majority of inter-row weeders use sweeps, weed knives, or shovels that dig 2-4 cm. Regular hoe blades, like duck foot blades, are fixed to either stiff or vibrating shanks. A gang, which is installed on a toolbar and typically consists of three to five shanks, cultivates an inter-row spacing. Rolling cultivators and PTO-driven cultivators can both be used for inter-row cropping [14].

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 [15].

Rotating weeders, like rotary tillers and rotary tilling, are another type that are frequently employed for inter-row weed control. The latter machine, however, costs more because it was made to perform numerous tasks, like strip planting into cover crops and creating 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 KARAVU). 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)” [16].

The basket weeder is an implement that consists of rolling rectangular-shaped quarter inch spring wire forming a round basket (Fig.1). This ground-driven basket weeder works similarly to sweeping-type cultivators. Without shifting soil into the crop row, the basket weeder will get rid of weeds that are growing at the top of the soil. This machine works best in moist soils with little clay. It performs weed control at forward speeds of 6.4 km/h (4 mile/h) to 12.9 km/h (8 mile/h) [16].

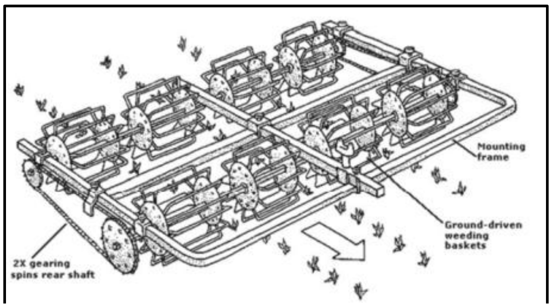

Fig. 1. Basket weeder for inter-row weed control [16]

The success of harrowing is based on the soil's a rid climate conditions. It can be used rather in late growth stages and timing is not crucial [17]. 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 [18]. 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 [9]. 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 the 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 [19]. 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* [9]. 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% [9]. 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 [20]. The hoeing implements are typically controlled by manual steering, which helps to minimise 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 [17].

2.2 Mechanical Intra-row Weeder

Weeds within crop rows are controlled with mechanical intra-row weeders. There are numerous tools available for weeding within rows. The majority are low-tech and are just pushed between the rows. The crop-weed selectivity factor has a significant impact on how well they perform.

Depending on the crop density, these kinds of implements achieve their purpose utilizing one of two different techniques. The first technique involves using specific equipment or auxiliary instruments to perform weed management in close proximity to the crop without endangering the crop itself. The weeder doesn't need to travel sideways when using this technique. The second method involves using machinery with sideways-moving weeding instruments to control weeds 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).

2.2.1 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 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 Figure s penetrate the soil just below the surface to remove small weeds. The finger mechanism works best in loose soil and less effectively in soils that are thickly crusted, compacted, or where there is a lot of residue. 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 [21] 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 [16,13], (Weide et al. 2008).

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

2.2.2 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 %" [39]. "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" [16,13], (Weide et al. 2008).

2.2.3 Brush weeders

Melander [18], they are designed with vertical brushes that are powered by hydraulic motors. Brush weeders use 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" [18,13].

Fogelberg and Gustavsson [22] studied the use of a brush weeder as 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 inBecause brush weeding uses a stronger uprooting force than the weed plants' root anchorage force, they came to the conclusion that uprooting was the primary method of weed management.

Kouwenhoven [23] 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 with the humid weather conditions, it resulted in additional weed plant appearance after the weeding operation.

2.2.4 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).

This machine is similar to the brush weeder described above, but uses a mechanical drive and does not require any hydraulic power. Because of its low price and low maintenance costs, it is an excellent choice for small-scale vegetable growers. 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 [23]. "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" [25]. The weed control efficacy has not yet been reported.

Fig. 3. ECO weeder requires an operator to move rotating weeding mechanisms with tines [24]

2.3 Cycloid Hoe Weeder

The cycloid hoe is a high-tech device for intra-row weeder [26]. "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" [27] (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" [27]. High quality bio-char can be produced from shredded cotton biomass by pyrolysis [28].

Griepentrog et al. [20] 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. [29] 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".

2.3.1 Bezzerides weeder

Schweizer et al. [30] 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" Schweizer et al. [30].

2.4 Automated Technology in Weeding Operation

"Weed control has benefited from the application of automation technology, which has combined manual and mechanical methods. By utilising automation, a machine provides the opportunity to identify and distinguish crop plants from weed plants while also removing the unwanted plants with a precisely controlled tool" [31]. Slaughter et al. [2] "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 of 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 can 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 hcan deliver a lateral positioning accuracy along the row with RMS error of 2.4 in and the extreme error distance of 13 cm" [2]. 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 are 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 [32] used an "environmentally adaptive segmentation algorithm (EASA) to develop real-time machine vision weed detection for outdoor lighting conditions". Tang et al. [33] 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" [34]. Development and performance evaluation of batch type biomass pyrolyser for agricultural residue [28].

2.5 Automated Mechanical Weeders

Tillett et al. [35] 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 the 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" [36].

Astrand and Baerveldt [34] 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".

At the back of the machine was a weeding tool, which was a rotating wheel placed perpendicular to the crop row. When a gap between crop plants was detected, a pneumatic cylinder was used to lower the tool, which then tilled the intercrop plant area. The weeding robot had strong perceptive abilities at a speed of 0.66 feet per second (0.72 kilometers per hour). Based on a row-recognition algorithm with a (0.8 in.) (2.0 cm) inaccuracy, the crop row detection camera was able to recognize crop rows. Utilizing image division techniques to distinguish between crops and weeds using color and shape data, the crop detecting color camera effectively found crops. However, they are not aware of the machine's effectiveness in weed management.

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. [13] 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 [37] 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" [38,39].

3. 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. The weeding mechanism of automated weeding machines has never required electrical power. However, the majority of the time, mechanical and fluid power have been used to control the weeding actuators. It is assumed that more accurate control of the weeding actuators may be achieved by using electricity and electronics. To understand how soil depth, actuator speed, and other factors affect needed power, the system's power consumption can also be monitored. In contrast to hydraulic systems, which are equally susceptible to hydraulic fluid leakage, electrical systems do not leak and do not contaminate the soil. Although the effectiveness of current mechanical non-automated weeding technology appears promising, there are certain other factors to take into account. To reduce crop damage, machinery like the finger weeder and torsion weeder need precise steering. Although they operate well, brush weeders need a back operator or operators to maneuver the brush into 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 logical progression for this idea, as it has the ability to significantly increase the effectiveness of weed management and reduce the likelihood of plant harm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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