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Avesh Kumar Singh
Assistant Professor, Regional Agricultural Research Station, Pilicode, Kerala, India

Anu Alphonsa Augustine
Assistant Professor, Regional Agricultural Research Station, Pilicode, Kerala, India

Aruna TN
Ph.D. Scholar, ICAR-Indian Agricultural Research Institute, New Delhi, India

Amit Kumar Gupta
SRF, ICAR-Indian Agricultural Research Institute, New Delhi, India

Utkarsh Dwivedi
SRF, ICAR-Indian Agricultural Research Institute, New Delhi, India

Corresponding Author:
Aruna TN
Ph.D. Scholar, ICAR-Indian Agricultural Research Institute, New Delhi, India

A review on integrated weed management practices-Mechanical and chemical methods

Avesh Kumar Singh, Anu Alphonsa Augustine, Aruna TN, Amit Kumar Gupta and Utkarsh Dwivedi

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Abstract
Agriculture forms the backbone of the Indian economy, with a significant portion of the population depending on it for livelihood. Despite advancements in technology, many essential farming operations-such as spraying, weeding, sowing, and reaping-are still performed using traditional methods. These practices are labor-intensive, time-consuming, and often inefficient. Although mechanization has brought considerable improvement in productivity, most advanced machines are expensive and unaffordable for small and marginal farmers who constitute the majority in India. Additionally, small landholdings limit the practicality of large-scale equipment. With the rising demand for food and increasing labor shortages in rural areas, there is a pressing need for affordable, compact, and multi-purpose machines that can perform multiple operations efficiently. This review explores the extent of work done in developing integrated systems, particularly for spraying and weeding. Such systems aim to reduce manual effort, conserve resources through precision application, and promote sustainable agricultural practices tailored for small-scale farming.

Keywords: Mechanization, spraying, weeding, integrated system, precision agriculture

Introduction

Weeds are major obstacles in successful and mechanical methods were the prevalent cultivation of cotton. Cotton is highly weed management techniques used by vulnerable to weed competition especially in farmers till the end of 1990s. During the 1990s, the nominal farm wages grew at 11.6% annually, while in the 2000s they rose at 8.9%. In the recent past, the growth was 17.8% during 2007-2008 and 20102011. The effect of increased wages and labor costs has concomitantly increased reliance on herbicides, applied alone or as a component of integrated weed management (IWM) [Rao *et al.*, 2014] [24].

Weeds are unwanted plants which affect the growth of a crop and reduce yield; thus, necessitating their control. Weeds are also identified as invasive plants. Weeds produce enormous numbers of seeds, assisting their spread. They are outstanding in reproducing and surviving in disturbed environments and are successful to colonise and dominate in diverse conditions. Throughout Punjab, weeds control is a major agricultural operation and their management is consuming considerable amount of resources. Climate change poses an additional challenge to manage weeds.

Weed management plays an important role for the successful cultivation of crop. India is a land of agriculture which comprises of small, marginal, medium and large farmers. The consumption of weedicide in India in 2016-2017 was 3290.87 metric tonne, which has been increasing significantly (Anon, 2017a) [2]. Weed control cost around Rs. 6000/ha for Kharif crops and around Rs 4000/ha for Rabi, which comes to the tune of 33% and 22%, respectively of the total cost of cultivation of the season (Yaduraju and Mishra, 2017) [34]. Depending upon the nature, density and period of occurrence of weeds, loss of crop yield can be 35-80% (Gupta *et al.*, 2006) [10]. If weed management practices are not adequate, then weeds can cause 30-40% reduction in the yield of kharif crops and 25% reduction in rabi crops (Dixit, 2012) [7]. It was studied that more than 30,000 species of weeds have been recorded in the world, out of which nearly about 18,000 cause serious damage in different ways, thus resulting in considerable losses in production of agricultural crops. Growth requirement of crops and weeds are identical. Therefore, when weeds are allowed to grow with crops, they significantly compete with crop plants for all the growth factors, natural or costly inputs. Resulting, weeds absorbs nutrients and moisture faster and smoother the crop plants leading to reduced yield. It has been estimated that losses due to weeds exceeds losses from any other pest or disease. Some of the weeds cause health problems and allergic reactions. They also markedly reduce the flow of water irrigation and drainage channels. Various weed management practises such as mechanical, biological, chemical, and agronomic (cultural) helps to prevent, eradicate and control the effect of weeds in crop. Mechanical and/or physical methods are used by small and marginal farmers such as hand pulling, hand hoeing, tillage, digging, burning, sickling and mulching" which causes labour intensive and environmental effects which also reduce health of farmers. Chemically backpack type power sprayers using flat fan or flood jet nozzles has been used by farmers for control in weeds during pre-emergence and post emergence. Controlling weeds through manual weeding and hoeing is effective, but with limitations such as timely availability of adequate labour and difficulty during rainy season. The commonly used is application of weedicides at need of time.

Small scale and marginal farmers generally use manually lever operated backpack sprayer and because of its versatility, cost and design. Manually they use khurpi, manually operated cultivator, wheel hoe and intercultural tools to get control over weeds. Tractor operated or self-propelled are also used for the mechanical control but they are not suitable for weeds found adjacent to the crop rows due to crop damage. Different types of tractor operated boom sprayers and hydraulic sprayers (gun type) are also popular due to wider swath width of spray but cannot be used when the crop is mature, due to less ground clearance of the tractor to take the advantage of wider swath of spray. Furthermore, the farmer commonly used manual operation and back pack type gun type power sprayer for spraying on weeds during pre-emergence as well as post emergences but they are not adequate for the weeds which occurs at the bottom of the crop as crop height covers them all. To overcome this problem, High clearance sprayers are available which can be used for tall crops but the cost of sprayer is very high (Mahal *et al* 2007) [15] and not in the budget of small and marginal farmer. The weedicide consumption in India needs to be decreased by adopting integrated weed management (IWM) and improving the spray efficacy. The reduction in consumption of weedicide will result in less cost of cultivation and will improve the quality of product (Anon, 2017b) [3]. The success of insect-pest, diseases and weed control depends upon use of proper spraying efficacy. Weeding is farm operation where mechanical methods of weed control are followed to provide best opportunity for the crop to establish and that helps to grow them vigorously up to the harvest. Weed management defines the approach where weed prevention and weed control have companion roles. It implies a system approach in which all available tools are used such as mechanical, chemical control to reduce the propagule seed bank, prevent weed emergence and minimise competition from weed growing with desired plants. Hence, there is need to develop a tractor operated weeder cum sprayer with marginal cost which can be used during post emergence for wider row crops.

Weed interference in cotton and maize

Weed infestation is one of the major limiting factors in crop production, particularly in cotton, which is highly sensitive to weed competition due to its slow initial growth. Perennial weeds, with their strong competitiveness for natural resources, significantly reduce the productivity of crops like cotton and maize. The early growth stages of these crops are especially critical, and maintaining weed-free conditions during this period is essential for achieving optimal yields. Cotton, being widely spaced and slow-growing at the start, is especially prone to severe weed competition, often resulting in lower yields. A study by Nadanassababady *et al.* (2001) [18] highlighted that the persistence of weeds in cotton fields is largely due to their wide adaptability to various climatic, edaphic, and biotic stresses, along with their high seed production and viability.

Chemical control of weeds

Chemical control of weeds plays a crucial role in sustaining crop productivity, particularly in Bt cotton and transgenic maize fields where diverse weed species aggressively compete for essential resources such as nutrients, light, and space. In Bt cotton fields, three main categories of weeds-broadleaf weeds, grasses, and sedges have been observed, with broadleaf weeds being the most prevalent, constituting 54% of the total weed population. Among them, Trianthema portulacastrum was identified as the most problematic species, contributing approximately 40% of the total weed density, followed by Digera arvensis, Amaranthus viridis, Cucumis prophetarum, Portulaca oleracea, and Tribulus terrestris (Cheema *et al.*, 2008) [5]. Grasses such as Cynodon dactylon, Dactyloctenium aegyptium, and Echinochloa colonum comprised 31%, while sedges, predominantly represented by Cyperus rotundus, accounted for 15% of the weed infestation. A similar trend was observed in transgenic maize and cotton crops, where broadleaf weeds consistently outnumbered grasses and sedges. Predominant species included Trianthema portulacastrum, Cleome gynandra, Digera arvensis, Datura stramonium, Cynodon dactylon, Dactyloctenium aegyptium, Commelina benghalensis, and Cyperus rotundus, with Trianthema portulacastrum remaining the dominant weed across both 2009 and 2010 growing seasons (Duraisamy *et al.*, 2013) [8].

Critical period of crop weed competition

The critical period of crop-weed competition is the stage when both the crop and the weeds grow simultaneously, competing intensely for essential resources like nutrients, water, and light. In cotton, this period typically ranges from 3 to 9 weeks after sowing and varies depending on environmental conditions and the biology of both crop and weed species. The presence of weeds for more than three weeks after crop emergence has been shown to significantly reduce crop growth and lint yield, as reported by Papamichail *et al.* (2002) [21]. Cotton is especially vulnerable to weed competition during the first 60 days of growth. Yield reductions between 33% and 40% have been observed under heavy weed infestations, with higher weed biomass per square meter in untreated plots compared to weed-free ones (Sivakumar and Subbian, 2002) [29]. Research by Poonguzhalan *et al.* (2014) [22] identified the critical weed competition period to be between 30 to 60 days after sowing, which represents nearly half of the crop's total growth duration. Yield losses were found to escalate as the duration of weed presence increased, with the highest losses recorded under full-season weed interference. Furthermore, Salgado *et al.* (2002) [26] noted that even an 8-day delay in weed control after emergence could reduce cotton yield by 5%, defining the Critical Period of Interference Prevention (CPIP) as between 8 and 66 days after emergence (DAE), and the Total Period of Interference Prevention (TPIP) extending up to 66 DAE.

Effect of weeds on growth, yield and attributes as well as quality parameters: Effective weed management significantly influences crop growth, yield attributes, and quality parameters. Although various pre-emergence and post-emergence herbicides are available, managing the complex weed flora in Bt cotton and maize requires appropriate combinations of both to ensure effective control during the critical weed competition period. Studies have shown significant yield improvements with integrated weed control strategies. For instance, seed cotton yield increased by 66-75% when pre- and post-planting weedicides were applied compared to untreated plots, as observed in a study by Bharathi *et al.* (2011) [4]. Poonguzhalan *et al.* (2013) [22] reported that unchecked weed infestations could reduce cotton yields by 40-85% due to severe competition for essential resources. Mechanical weeding, when conducted thrice at 20, 40, and 60 days after sowing (DAS), resulted in higher boll numbers, kapas yield, and better economic returns, with the next best results seen under pre-emergence application of pendimethalin, according to Leela *et al.* (2016) [14].

Spray application methods also impact pesticide effectiveness and crop health. Miller and Butler (2000) [16] demonstrated that air characteristics and spray volume distribution patterns significantly influence droplet retention, efficacy, and drift potential. They found twin-fluid and air induction nozzles to be more sensitive to spray liquid properties than conventional hydraulic nozzles. Tahir *et al.* (2009) [30] identified manual hoeing, stomp 35-EC, and Pendimethalin + Prometryn combinations as the most effective for weed control in spring maize, significantly boosting grain yield. Hassan and Bushra (2010) [11] highlighted how increased spray pressure and forward speed positively influenced droplet density and distribution, affecting pest control outcomes. Similarly, Singh *et al.* (2010) [28] reported better droplet deposition and whitefly control with a tractor-mounted air-assisted sprayer compared to a conventional system.

Innovative sprayer technologies have been developed to enhance precision and efficiency. A tractor-operated target-actuated sprayer by Jayashree and Krishnan (2012) [12] reduced off-target chemical applications, yielding fine sprays with minimal environmental impact. Safari *et al.* (2013) [27] evaluated various boom sprayers and found that air-assisted models ensured comprehensive canopy coverage and higher pest mortality, although they showed more drift compared to turbo-liner sprayers. Poratkar and Raut (2013) [23] introduced a manually operated multi-nozzle sprayer, improving uniform pesticide application while minimizing physical strain and chemical overuse.

In UAV applications, Faiçal *et al.* (2014) [9] developed an adaptive algorithm that adjusted UAV routes based on wind conditions using feedback from a wireless sensor network, thereby minimizing pesticide and fertilizer waste. A self-propelled boom sprayer evaluated by Karale *et al.* (2014) [13] in cotton and chilli fields demonstrated high field efficiency and reduced labor costs. For smallholders, Veerangouda *et al.* (2014) [32] designed a bullock-drawn engine-operated high-clearance sprayer suitable for pigeonpea crops, which offered cost-effective spraying within physiological limits for draft animals. For greenhouse use, Wandkar *et al.* (2015) [33] developed an air-assisted sleeve boom sprayer that achieved uniform spray coverage with optimal droplet size at specific air velocities and pump discharges.

Lastly, effective weed control in maize was also demonstrated by Patel *et al.* (2016) [20], who reported over 98% weed control efficiency using a combination of pre-emergence applications of atrazine, pendimethalin, and alachlor, along with two rounds of hand weeding.

Mechanical control of weeds

Mechanical methods of weed control offer effective and economical alternatives to chemical approaches, particularly in crops like maize and rice. Among various manually operated weeders evaluated in maize, the wheel hoe demonstrated superior performance, resulting in a 154% increase in grain yield compared to the untreated control. It also required the least time for operation (71.43 hours/ha), covered the largest area, and incurred the lowest operational cost (₹714/ha) when used twice at 25 and 45 days after sowing (DAS), yielding results comparable to pre-emergence application of atrazine at 0.5 kg/ha followed by hand weeding at 45 DAS, as reported by Myanavathi *et al.* (2008).

In a study on mechanized weeding tools, the development and evaluation of a rotary power weeder revealed a weeding efficiency of 73% and a field capacity of 0.0712 ha/h. The operational cost using this equipment was significantly lower (N 2,700/ha) compared to manual weeding (N 12,000/ha), according to findings by Olaoye and Adekanye (2011) [19].

Further assessment of mechanical weeders in paddy fields revealed notable differences in performance among equipment types. Alizadeh (2011) [1] compared single-row conical, two-row conical, rotary, and power weeders with conventional hand weeding. The highest weeding efficiency (84.33%) was achieved with the power weeder used in a hybrid rice variety, while the lowest efficiency (72.80%) was observed with the rotary weeder in the Hashemi variety. Although mechanical methods resulted in slightly higher plant damage (3.83%) compared to hand weeding (0.13%), the power weeder recorded the highest effective field capacities (0.082 and 0.087 ha/h for Hashemi and Hybrid, respectively), while the hand weeding treatment had the lowest (0.0084 and 0.0088 ha/h). Additionally, the cost of weeding was reduced by 15.70% (single-row conical), 38.51% (two-row conical), 22.32% (rotary), and 48.70% (power weeder) in comparison to hand weeding.

Integrated weed management

Integrated weed management (IWM) is a sustainable approach that combines multiple direct and indirect control measures based on the critical period of crop-weed competition, and has been increasingly adopted by farmers in cotton and maize cultivation. This method encompasses various weeding operations, evaluates their effectiveness, and considers future advancements in weed science, particularly within the Indian context. The focus includes weed species commonly associated with cotton and maize, their critical stages of interference, potential yield losses, cost-benefit analyses, and appropriate management practices. It also examines the current status of weed research, adoption challenges, and opportunities for improving weed control strategies.

According to Rao and Nagamani (2010) [25], IWM is a science-based decision-making process that incorporates macro- and micro-environmental data, weed biology and ecology, and available technologies to manage weeds in the most economically viable and ecologically sound manner. They emphasized that Indian research on IWM must extend beyond herbicide-based approaches and instead focus on understanding weed behavior, herbicide resistance, transgenic crop impacts, and environmentally sound practices. Their findings indicated that combining herbicides with hand weeding provided the most cost-effective weed control solution.

Thomas *et al.* (2010) [31] highlighted that the foundation of IWM lies in utilizing a thorough understanding of weed-crop dynamics and agroecosystem principles. By applying a diverse array of control tools, the system aims to shift the competitive advantage toward the crop and away from undesirable species like weeds.

Observations by Chinnusamy (2014) [6] revealed that herbicide-tolerant crops, developed through biotechnological methods, have become increasingly important. These crops enable farmers to adopt reduced or zero-tillage systems and minimize the usage of environmentally hazardous herbicides, while still effectively managing a broad spectrum of weed species. Although the technology is still in its early stages of field evaluation in India, efforts are underway to assess its agronomic benefits and management potential.

While chemical spray methods remain the preferred choice for weed control, their effectiveness is often limited in areas where weeds are shielded by crop canopies. Mechanical weeders, on the other hand, offer additional advantages such as improved soil aeration and reduced environmental impact. However, their ability to access weeds located near crop rows is restricted due to the potential risk of damaging the crops.

Conclusion

Weed management is vital for sustaining high productivity in Bt cotton and maize. While chemical, mechanical, and cultural methods individually offer benefits, their limitations make Integrated Weed Management (IWM) the most effective and sustainable approach. IWM combines timely use of herbicides, mechanical tools, and ecological practices based on the crop's critical weed competition period, reducing yield losses and environmental risks. The review shows that integrated strategies enhance weed control efficiency, improve yield and quality, and lower input costs. Moving forward, emphasis should be placed on farmer training, eco-friendly technologies, and research on herbicide resistance and transgenic crop compatibility to ensure long-term sustainability in weed management practices.

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