Chapter

Weed Interference and Management in Cucumber (*Cucumis sativus* L.)

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Abstract

Weed interference is a major problem in cucumber farming, leading to 45–95% yield reduction. Weed control practices employed to avoid such losses are predominantly hand weeding and herbicides application. All the weed control methods used in cucumber farming have their own limitations. Hand weeding is tedious, time consuming and associated with high labor demands. Only few herbicides are registered for weed control in cucumber, and these herbicides does not provide season-long weed control when used alone, neither can they control the entire weed spectrum with diverse physiology, morphology and time of emergence. Therefore, to optimize yield, financial and environmental costs and benefits, integrated weed management approaches are advocated. A good tillage operation, use of competitive cultivars, appropriate plant population and row spacing, application of pre and post emergence herbicides are important in reducing weed density. The combination of these approaches provides effective weed control, and helps in environmental conservation. The world is now moving toward precision weed management techniques which involve remote sensing, modelling and use of robotics to control weeds. These technologies are the future of weed management in crop production and have a substantial role to play in modern cucumber production. Right selection of one or more of these techniques with reference to environmental, socioeconomic, and geographic conditions will provide effective weed control in cucumber. Future research should therefore be focused on delivering information for the implementation of these approaches.

Keywords: Weed competition, hand weeding, herbicides, integrated weed management

1. Introduction

Weeds are one of the most important pest that reduces crop productivity. Weeds and crop plants are very similar in their demand for carbon dioxide and nitrogen from the atmosphere, water and minerals from the soil and light from the sun for their growth and development [1]. When weeds compete for these restrictive resources, the growth and development of crops are restricted, and their yield and productivity drastically reduced. The type and density of weed population, and the duration of weed-crop interference determines the magnitude of damage and yield loss inflicted by weeds on crop plants [2, 3]. Weed interference in cucumber results

in high yield reduction in the range of 45–95% in different agro climatic conditions [4–6]. Growers and agricultural experts throughout the world consistently indicate that weeds are one of the most economically important pests of cucumber. Therefore, an effective weed management strategy is recognized as a necessity for an economically feasible cucumber production [4, 6].

Currently, weed management methods employed to reduce yield losses in cucumber are predominantly hand weeding and herbicides application [7]. However, these weed management systems have a number of limitations. Hand weeding is tedious, inefficient, time consuming and associated with high labor demands [1, 7, 8]. In addition, labor for manual weeding is scarce and often too expensive [1, 2, 9]. Consequently, farmers spend a large amount of time in weeding operation. Despite the effort expended in weeding by farmers, weed still cause considerable yield losses, because most of the weeding operations are not done during the critical period of weed interference, but well after the crop have suffered irrevocable damage from weeds [4, 10]. Most weed competition in cucumber is a consequence of delayed first weeding during the early stage of crop growth [7, 11]. Moreover, the efficacy of hand weeding is often compromised by the continued wet condition characteristics of the beginning of the rainy season in many agro climatic zones. Hand weeding under conditions of irrigation or high rainfall often causes weed to re-root and re-establish, necessitating several rounds of weeding to keep cucumber weed-free and avert yield losses [5].

Herbicides are quite effective in suppressing weeds in cucumber if used properly [7]. Herbicides reduce drudgery and protect cucumber from early weed competition [4, 10]. However, only a few herbicides are registered for weed control in cucumber [12, 13]. Moreover, most available herbicides do not provide season-long weed control when used alone, and single herbicide application may not control the entire weed spectrum with diverse physiology, morphology and time of emergence [4, 6, 14]. Although herbicide use alleviates the problem of labor for weeding, incorrect use may be injurious to the crop and bring about other environmental problems [15, 16].

No-tillage, conventional tillage, stale seedbed, and mulching are other options currently utilized for weed control in cucumber [15–18]. However, these weed control methods are limited and inefficient when used as a stand-alone weed management tactics [5]. Therefore, the adoption of integrated weed management (IWM) strategy is more advantageous than relying on one form of weed control. IWM involves the reduction of weed interference through a combination of two or more methods while maintaining acceptable crop yields, environment, social and economic wellbeing [1, 19]. However, in literature, information on weed interference and management methods, especially IWM strategy for improved productivity of cucumber is very scattered and not available in the form of a single document. Therefore, this book chapter is compiled to present all the available information into one document, which will be useful to all cucumber industry stakeholders like researchers, academicians, the extension community, industrialists, and growers. This book chapter covers in detail the weed flora of cucumber, their impact on cucumber and yield losses due to weed interference, different methods of weed control and IWM management strategies in cucumber.

2. Weed flora of cucumber

Diverse weed species infest cucumber but the extent of damage inflicted on cucumber crop varies with the type of weed species involved. A complete list of weed flora in cucumber grown in different agro climatic zones around the world is

Weeds	**References**
Abutilon theophrasti Medicus	[20, 21]
Adconopus compressus	[5, 22]
Ageratum conyzoides	[22, 23]
Ambrosia artemisiifolia L.	[5, 20, 23]
Amaranthus hybridus L.	[5, 22–26]
Amaranthus spinosus L.	[5, 23–25]
Amaranthus palmeri S. Wats.	[4, 23–25]
Amaranthus lividus L.	[5, 24, 25]
Amaranthus retroflexus L.	[23–25]
Ambrosia artemisiifolia L.	[22, 23]
Anodacristata L.	[20, 24]
Aspilia Africana	[22]
Axonopus compressors (Sw.) P. Beauv	[22, 27]
Bidens pilosa	[22, 23, 27]
Boerhavia diffusa (Linn).	[22, 27]
Chenopodium album L.	[20, 22, 23]
Chloris pilosa Schumach	[27]
*Chromoleana odorata (*L.) R.M. King and Robinson	[22]
Chrysopogan aciculatus (Retz.) Trin.	[27]
Combretum hispidum Laws.	[27]
Commelina benghalensis (Burn.)	[20, 24]
Commelina diffusa L.	[22]
Commelina errecta L.	[24]
Convolvulus arvensis L.	[23]
Coronopus didymus	[27]
Croton hirtus L'Herit	[23]
Crupheacarth agenensis	[24]
Cynodon dactylon L.	[22–24]
Cyperus esculentus L.	[5, 23, 24]
Cyperus rotundus L.	[5, 20, 22, 23, 26]
Digitaria horizontalis Willd.	[24]
Echinochloa crusgalli	[23]
Euphorbia heterophylla L.	[27]
Euphorbia hirta	[27]
Euphorbia glomerifera	[27]
Eleusine indica L.	[22]
Emilia sonchifolia	[20, 24]
Emilia coceinea	[22, 24]
Eragrostis atrovirens	[22]
Galinsoga spp	[20]
Impereta cylindrical	[27]

Weeds	References
Ipomoea spp	[26]
Ipomea triloba L.	[27]
Jamaica vervain	[27]
Laportea aestuans	[22]
Mimosa diplotricha C. Wright ex Sauuville	[22]
Mimosa pudica	[22]
Paspalum conjugatum	[22]
Paspalum scrobiculatum L.	[27]
Panicum maximum Jacq.	[22]
Portulaca pilosa	[27]
Portulaca oleracea	[20, 23]
Phyllantus samarus	[22, 23]
Seteria verticillata	[23]
Spigelia anthelmia L.	[23, 27]
Sida acuta	[22]
Solanum carolinense	[24]
Solanum nigrum	[23, 24]
Sonchus oleraceus	[24]
Sorghum halepense	[23],
Starchyptophetae ayenesis	[22]
Talinum triangulare (Jacq.) Willd.	[20]
Tribulus terrestris L.	[23]
Tridax procumbens	[22]
Xanthium strumarium L.	[5, 20]

Table 1.
A list of weed flora of cucumber.

presented in **Table 1**. However, major problematic weeds in cucumber include broad-leaved weed species such as members of the families Amaranthaceae (*Amaranthus retroflexus*, *Amaranthus spinosus*, *Amaranthus hybridus, Chenopodium album*) Asteraceae (*Tridax procumbens*, *Bidens pilosa, Xanthium strumarium, Ambrosia spp*); Euphobiaceae (*Euphorbia heterophylla*, *Euphorbia hirta*); Convolvulaceae (*Ipomoea spp*, *convolvulus arvensis*); Portulacaceae (*Portulaca oleracea, Purtulaca pilosa*); Solanaceae (*Solanum carolinense Solanum nigrum*), grasses weed species of the family Poaceae (*Cynodon dactylon*, *Sorghum halepense, Echinochloa crusgalli, Seteria verticillata, Digitaria spp, Paspalum spp, Panicum maximum*) and sedges of the family Cyperaceae including *Cyperus rotundus,* and *Cyperus esculentus* [24, 27–29]. The major feature of these weed species is their widespread existence and difficulty in management. Annual broad-leaved weeds like *Amaranthus spp, Chenopodium album, Solanum nigrum, Portulaca oleracea* and *Euphorbia spp* cause serious damage to cucumber due to their rapid spread, production of many seeds, high efficiency in water use and net photosynthesis [4, 5, 24, 27]. Just 1–2 plants of *Amaranthus spp* per square yard growing with cucumber throughout the crop life cycle can reduce yield by 10%, while 5–7 plants of *Amaranthus spp* per square yard can reduce cucumber yield by 50% [5]. The occurrence of many biotypes of this weed specie

and its resistance to sulfonylurea herbicides also complicates its management [25]. *Chenopodium album* is able to outgrow cucumber and compete with the crop for nutrients, light and moisture. Its rapid growth and establishment rate makes it difficult to control by cultivation [20]. *Solanum nigrum* also grows rapidly and is able to out compete with cucumber vines. It is also capable of hosting pest such as white fly [20, 25]. *Portulaca oleracea* spreads quickly due in part to its large seed it production. It also harbors pest such as caterpillar moths and spread quickly between the crop rows [20]. *Bidens pilosa* is another broad-leaved weed specie with great adaptability and one of the most difficult to control in cucumber [20]. Its main features are: the extensive formation of achenes, high water use efficiency in region of prolonged drought stress and dormancy which facilitates its viability in the soil. *Bidens pilosa* is also resistant to herbicides that inhibit the acetolactate synthase, which further makes it difficult to control in cucumber [20, 30].

Generally, annual weeds are the main problem in cucumber but perennials such as *Cyperus rotundus, Cyperus esculentus*, *Sorghum halepense Cynodon dactylon* and *convolvulus arvensis* are also difficult to control and possess considerable problems to cucumber [24, 25, 27, 29]. These weed species remain alive for more than one year in spite of producing seeds in the growing season proceeding the dry season and, therefore cause significant damage to cucumber. They are difficult to control because they have the capacity to survive adverse conditions by forming extensive underground vegetative structures such as rhizomes and stolon [31]. *Cyperus rotundus,* and *Cyperus esculentus* can reproduce sexually and asexually by rhizomes and tubers, and therefore exert significant competition for moisture, carbon dioxide, light and nutrient in addition to their allelopathic effects [31]. Competition and allelopathic effects of *Cyperus rotundus* at high density may reduce cucumber yields as much as 83% [32].

3. Effect of weed interference on cucumber

Weed interference is the detrimental effects of weed on crop resulting from their interaction with each other. Weeds are considered as the most harmful pest of crops, and their interaction with crops have considerable consequences on the economy, society, and the environment [33]. They limit crop productivity and profitability, alter the ecosystem function and hamper the sustainability of the agricultural system. Yield losses and reduced profitability due to weed interference is considered one of the major problem in cucumber production [10]. Even with advanced technologies, producers record high losses due to weed interference. According to estimates, between 45–95% potential yields of cucumber is lost due to weed interference depending on the type and density of weeds growing in the crop community, duration of weed interference, stage of crop growth at which the interference takes place and the crop variety [4, 22]. Generally, losses due to weed interference in cucumber can either be direct or indirect. Direct losses due to weed interference includes damages caused by weed's allelopathic interaction with cucumber and competition for growth resources such as nutrients, water, light and space [5, 10]. Weed interference affects cucumber production indirectly by sheltering crop pest and diseases, interfering with timeliness and efficiency of harvest, increasing harvest difficulties, reducing fruit quality and consequently increasing the cost of processing [34, 35]. Weeds are potential source for diseases and pest including powdery mildew (*Podosphaera xanthii*), gummy stem blight (*Didymella bryoniae*), fungal root rot (including *Pythium, Rhizoctonia* and *Fusarium*), thrips (Thrips palmi) which may be hosted by a variety of weeds including *Portulaca spp, Amaranthus spp*, *Gomphrena celosioides* and white fly [36–39].

Weed interference in cucumber begins during the very early stages of vegetative growth [5]. Unfortunately, cucumber is not a strong competitor at the early stage, therefore weeds out grow them during the early stage of crop growth, resulting in high yield reduction [4]. Weeds that germinates at the same time as cucumber such as annual weeds like *Amaranthus spp*, *Xanthium strumarium* and *Ambrosia artemisiifolia* grows faster and maintain canopy above and below the top of cucumber. Hence, these weeds intercept photosynthetically active radiation at the expense of the crop, resulting in reduced yield [40, 41]. Furthermore, weed-inflicted shading of cucumber flowers promotes flower abortion. Although cucumber becomes less vulnerable to weed competition after the vines run out or when they become well established, the crop may take a few more weeks to close canopy. Weeds that emerge during this period may complicate harvest by concealing fruit or hampering manual picking with prickly foliage, or entangling vines, and promote fungal diseases by limiting air circulation. *Solanum carolinense* is a host for cucumber powdery mildew fungus (*Erysiphecichor acearum*), and many common weeds such as *Amaranthus spp* and *Cyperus spp* can carry cucumber mosaic virus [42].

4. Critical period of weed control (CPWC) in cucumber

The CPWC is a period in the crop growth cycle during which weeds must be controlled to prevent quantitative and qualitative yield losses [21]. It is the period when a crop is most sensitive to weed competition and therefore the time interval when it is necessary to maintain wed-free condition to prevent an unacceptable reduction in potential yield [23]. It denote the optimum timing of weed removal to prevent potential yield loss. From practical standpoint, crop yield losses from weed interference before or after the CPWC will be of limited interest. This means that weeds that are present before or emerge after the CPWC do not cause significant yield loss [43]. Studies conducted on cucumber [5, 44] have shown that weed infestation during the CPWC imposes irreversible loss and damage on the final yield, while weed control before or after the CPWC did not improve fruit yield compared with crops kept weed-free only during the CPWC [45, 46]. Weed control recommendations in cucumber are therefore made on the basis of the CPWC because they indicate the optimum time for implementing and maintaining weed control at reduced cost [47]. Although published research work on weed interference and CPWC in cucumber are very limited in the literature, the few available studies [4, 5, 45, 48] have shown that the CPWC in cucumber varies across environment (location, soil, climate and management), infesting plant community (species, density and population), crop (cultivar, spacing and density), growing seasons and years [44–48].

In the USA, the CPWC in cucumber was estimated to be between 4 and 6 weeks after sowing [49–51]. In another study, it was determined that cucumber maintained weed-free for as little as 2 weeks after sowing (WAS) produced yield similar to the season-long weed-free treatment [52]. The author found that a single weeding either 3 or 4 WAS was sufficient to prevent yield loss for cucumber planted on 1.2 m row spacing, and concluded that no CPWC existed. Conversely, cucumber in a narrow row spacing had a 3 to 4 WAS CPWC [52]. It was reported that the CPWC for cucumber was longer at a higher plant population than in a lower plant population [52]. In Canada, the CPWC for cucumber was determined to be between 12 to 36 days after sowing (DAS) with a mixed population of common ragweed and common lambsquarters [45]. In Brazil, it was found that the CPWC was between 3 to 7 WAS [53]. Due to the disparities in the results of the CPWC from one study and location to the other, it has been recommended that critical period of weed

interference should be determined specifically for a particular region considering the weed composition and climatic condition in order to provide precise information for growers [54].

5. Weed management in cucumber

5.1 Preventive weed management

Preventive measures of weed control is an important part of weed management that has gained attention among cucumber growers and weed scientist in recent time. Preventive weed control involves techniques and practices that hinders the build-up of weed species [55]. These involves clean cultivation through the use of clean water, seeds and fertilizer, and keeping the farm environment free from weeds and their seeds [56]. It is necessary to begin preventive weed control during the year before the beginning of cucumber production and use cucumber seeds free from weed seeds to promote a weed-free cucumber crop in the preceding season. The selected field must be relatively free from weed species such as nut sedges, Bermuda grass, morning glories and Johnson grass. Seed set by pigweeds, common cocklebur and other aggressive annual weeds must also be avoided as a precautionary measure to achieve a weed-free cucumber field [49]. Other preventive weed management measures in cucumber includes not growing cucumber the year after another annual vegetable with similar tillage cultivation and harvest schedules, especially in a highly infested field. Cultivation fallow can also be used to reduce the weed seed bank in cucumber fields that are heavily infested with weeds. The choice of cucumber variety can also affect the level of weed infestation. Hence, vigorous varieties with good adaptation to the prevailing local conditions and good foliage to suppress weed should be selected [49, 56]. Optimum conditions that give cucumber a competitive advantage over the weed species must be provided to prevent build-up of weed species. Fertilizer application method and timing must be manipulated in such a way that the nutrients are available to the crop rather than the weeds. In-row drip irrigation and fertigation can be used to water and apply nutrients to the cucumber and not the inter-row weeds [42]. Measures should also be taken to use water free from weed seeds. Large amount of rapidly available nitrogen, phosphorus and potassium fertilizers that can stimulate excessive weed growth in nutrient responsive weeds such as pigweeds common cocklebur, common ragweed and lambs quarters should be avoided [42]. Many weed species have higher water use efficiency than cucumber, hence flood irrigation should be avoided because they provide conducive environment for weed to flourish. Furthermore, weeds should be removed before they set seeds to avoid weed seed spread in the cucumber crop. Removing weeds in their early growth stages prevents them from setting seeds and spreading these to other areas of the field. Therefore, it is necessary to remove weeds the first time they have been noticed [42, 49, 56].

5.2 Cultural weed management

Cultural weed control is among the most important means of weed management used easily by most cucumber farmers. Cultural control is the use of common practices such as crop rotation, variation of crop row spacing, competitive cultivars adapted to climate and regional conditions, live mulches, cover crops etc. for the proper management of weeds, water and soil [57]. There has been a growing interest in cultural weed control methods during the last two decades as a result of the increasing concern of pesticide use. Cultural practices are regarded as the second

most environmentally friendly weed control method next to preventive measures. Cultural techniques help the cucumber farmers to reduce the cost of weed management. These techniques can affect weed-crop interaction and inter-relationship particularly during the critical period of weed control. These techniques provides favorable and conducive environment for the growth of cucumber and give the crop a competitive advantage over infesting weed species. Cultural weed control methods are easy and cost–effective in cucumber production. Crop rotation, primary tillage, soil solarization, high plant population and manipulation of sowing dates and row spacing are cultural techniques that can easily control weeds in cucumber production [21, 46, 50].

5.2.1 Crop rotation

Crop rotation enhances cucumber productivity by improving weed control and soil productivity. Continuous cultivation and tillage systems have negative interaction with each other and results in a shift in weed species composition with consequence difficulty in weed management [58]. A shift from cucumber to other crops of different life cycle, physiology and morphology serves as an important means of preventive weed control when cucumber is grown over time in the same field [42]. This practice has potential to reduce weed density and biomass, particularly when a competitive crop is rotated and an effective direct weed control tillage system is applied [5, 41]. On the other hand, continues cropping increases the risk of resistant weeds as a result of the application of similar cultural practices and herbicides of same chemistry for longer periods [21]. Broad-leaf weeds which are difficult to control in cucumber and other vegetables can be controlled readily in cereal crops. Crop rotation is particularly important in cucumber production because of its disease control benefit and weed control flexibility [59]. Cucumber-tomato, cucumber-pepper and cucumber-eggplants, rotation in farmers' fields showed that the rotation of cucumber with other vegetable crops is agronomically practicable, sustainable, and an eco-friendly technique for better weed control and economic benefits [59, 60].

5.2.2 Primary tillage

Primary tillage is an integral part of cucumber production system that enhances field preparation for planting operation. The tillage system used directly affect soil structure, plant available moisture and intensity of weed problem. Soil inversion during tillage is considered to be very beneficial for weed control [61]. The implement used and the depth of the tillage operation determines the impact of primary tillage in cucumber farming. The use of moldboard plough is an effective way to reduce weed density during the early growth stages of the cucumber crop [61, 62]. Weed densities and biomass are usually higher in zero or minimum tillage systems than in conventional tillage systems that involves the use mold plough [10, 61–63]. It was reported that cucumbers planted into no tillage rye had greater weed size compared to conventional tillage [61]. Reduced tillage was also reported to encourage increased perennial weed species in weed population in cucumber fields compared with conventional tillage [61, 62].

5.2.3 Stale seedbed

The use of stale seedbed is another cultural practice for suppressing weeds in cucumber. A stale seedbed is defined as a seedbed prepared several days, weeks, or month prior to planting or transplanting a crop [64]. In this method, resurgent

weeds in ploughed field are controlled by the use of tillage while irrigation or rain are used to stimulate weed seed germination. The flush of young seedlings is then killed by using shallow tillage or herbicides [65]. This method has been successfully used to reduce competition of several weed species including *Palmer amaranth*, and yellow nutsedge in cucumber [32]. Stale seed bed reduced weed infestation with the applications of glyphosate and paraquat on the seedbeds to control emerged weeds [66].

5.2.4 Soil solarization

Soil solarization is another non-chemical weed control technique in cucumber production. This technique involves hydrothermal disinfection of moist soil by transparent polyethylene sheets during the hot summers. These sheets entrap the sunlight and increase the temperature of upper layers of the soil by 8–12 °C compared with the non-mulch soil. The elevated temperature kills some of the seeds and breaks the dormancy of others. While the solar scorching kills the newly emerged weed seedlings [67]. Soil solarization is a simple, non-hazardous method that avoids the use of any toxic materials, does not contaminate the site and therefore suited for organic cucumber farming. The effectiveness of this method of weed control has been reported in cucumber crop [68, 69]. Soil solarization proved to be an excellent method for complete control of parasitic weed specie such as Egyptian broomrape (*Orobanche aegyptiaca*) and other weed species such as *Sorghum virgatum, Chenopodium album, and Purtulaca oleracea* infestation in cucumber [68–70].

5.2.5 Plant density and row spacing

Manipulation of crop row spacing and planting density can restrict weed seed germination and enhance the crop competitive ability against weeds [71]. Narrow row spacing and high plant densities are important techniques in enhancing cucumber competitiveness and suppressing weed growth [16, 72, 73]. These techniques are very cost-effective and environmental friendly. When the optimum plant population density is used through appropriate row spacing, cucumber crop is able to develop canopy cover and hence competitive advantage over emerging weed seedlings [73]. Narrow row spacing is known to suppress weed growth by closing crop canopy earlier than wide spacing. Early canopy cover by closely spaced cucumber has been shown to smother weeds, hence reducing weed-crop competition [16, 74]. Cucumber planted at narrow plant spacing of 1 m × 0.3 m resulted in earlier canopy closure and better weed suppression than those planted at 1 m × 0.6 m and 1 m × 0.9 m [73]. In another study, spacing of 75 cm × 25 cm resulted in weed density and biomass suppression compared to spacing of 75 cm × 50 cm and 75 cm × 75 cm in cucumber [73]. Herbicides work well with narrow spacing as it impacts the weeds by decreasing their vigor due to high competition with the cucumber plants in narrow row planting compared to the wide row planting [73, 74].

6. Mechanical weed management

Mechanical weed management involves the physical removal of weeds from the field by hand pulling or through the use of farm tools and implements such as hand hoes, cutlasses, cultivators, choppers, mowers disks or weeders [75, 76]. Mechanical weed management is one of the oldest weed control practice. It involves the practices of primary and secondary tillage. With mechanical weed

management, weeds in fallow fields are killed and the weed seeds buried in deep soil layers where they cannot emerge. Mechanical weed control in cucumber also involves plowing or disking to destroy weeds by exposing them to variations in light, moisture and temperature [77]. Secondary tillage practices such as harrowing is also used to dislodge and shred weeds in cucumber field. Although these practices destroys weed quickly, they do not provide season-long effect because some weed seeds are still present close to the soil surface [77]. It is therefore imperative to use mechanical weed management before or during early flowering to prevent the production of large quantity of weed seed, and engage follow-up weed control practices to achieve effective weed control. The best practice is usually to cultivate cucumber at the preliminary stage of weed growth when the weeds are still physiologically immature to exert significant competition with the crop [65]. Mechanical weed control cannot be used as the singular method of weed management because it may provide favorable conditions for emergence and dispersal of dormant weed seeds. It also impact the soil structure negatively resulting in soil dryness and compaction [65]. Hence, mechanical weed control must be used only as a supplement to other weed control practices within the context of integrated weed management.

7. Chemical weed management

Chemical weed management in cucumber is mainly through the use of herbicides of different active ingredients. Although only limited herbicides are registered and available for weed control in cucumber, herbicides are an essential component of a successful weed control program in cucumber production [78]. These herbicides either pre-emergence or post-emergence, when applied at correct dosage and appropriate timing hampers weed growth and development [6, 7]. Herbicides use in cucumber reduces drudgery and labor requirement, and makes weed control easy, efficient and economical. It also improves soil structure by boosting soil moisture and reducing soil erosion. However, effective weed control with the use of herbicides is limited by the potential for crop injury from registered herbicides [7, 28,]. Herbicides application at too high rate can damage cucumber while too low rate will not provide the expected weed control [5]. Best results from herbicides application in cucumber are obtained when the weeds are at their highest susceptible stages and the crop is at its highest tolerance stages. Selection of a suitable herbicide program for cucumber depends on the population, growth stage, biology and ecology of the infesting weed species [10, 14, 15]. Much of chemical weed control in cucumber revolves around two key herbicides: ethalfluralin and clomazone which gives a reasonable control over most weeds [20]. Both herbicides are safe to use on cucumber and are generally applied pre-emergence for grass and broadleaved weed control [34]. Pre-emergence and post-emergence herbicides are used for effective weed control in cucumber. Pre-emergence herbicides can be applied before the planting of cucumber. These herbicides remain active in soil and provide control of weeds before they emerge. However, pre-emergence herbicides should be used with extreme care as they can damage the cucumber seedlings [5, 20]. Although pre-emergence herbicides such as N-1-naphthylphthalamic acid (naptalam) provides satisfactory control of the grasses and broadleaved weeds, erratic performance of the herbicide was observed in cucumber [79, 80]. Cucumbers were tolerant to 3.4 to 4.5 kg/ha of naptalam applied immediately after seeding but were injured by applications at emergence or vining [79, 80]. Reduced yields and crop injury with pre-emergence applications of CDEC at 4.5 kg/ha was also reported in cucumber [79, 80].

Registered herbicides for broadleaf weed control in cucumber include halosulfuron, clomazone, ethalfluralin, bensulide, paraquat, carfentrazone and glyphosate. Glyphosate, paraquat, and carfentrazone are effective on *Palmer amaranth* when applied as post-emergence herbicide. However, these herbicides are only registered in cucumber for non-selective control of emerged weeds pre-plant, pre, or post along the crop rows with the use of spray guard [81–83]. These herbicides lack residual control and have limitations when applied post-directed [20], including the failure to control weeds beneath or closes to the crop canopy. Therefore, additional post herbicides that are non-toxic to the crop would be beneficial. Halosulfuron is registered for pre and post-emergence control of some *Amaranth* species [84] but does not give an effective post-emergence control of *Palmer amaranth* [85]. Clomazone has poor efficacy on *Palmer amaranth* when applied alone [85, 86]. Ethalfluralin applied as pre-emergence herbicide provides good early season control of *Palmer amaranth* [87]. Bensulide is an herbicide used as pre-emergence in cucumber and can be tank-mixed with naptalam. Bensulide primarily controls annual grasses, with suppression of only three broadleaf weeds [88]. Bensulide may persist in the soil for months, which may result in potential injury to cucumber [34].

Farmers also often use a combination of clomazone and ethalfluralin for weed management in their cucumber production. Clomazone applied alone suppresses several annual broadleaf weeds and grasses. Clomazone controls *galinsoga* species (Galinsoga spp.), common lambsquarters (Chenopodium album L.), spurred anoda (Anodacristata L.), and velvetleaf (Abutilon theophrasti Medicus.) [20]. However, the herbicide has potential to injure cucumber and adjacent vegetation as a result of volatilization and drift. Ref. [46] found that clomazone caused chlorosis in cucumber plants, though recovery was rapid. Similar to clomazone, ethalfluralin provides efficient control of many broadleaf and grass weeds and may injure cucumber. Carpetweed (*Mollugo verticillata* L.), common lambsquarters, pigweed spp. (*Amaranthus* spp.), common purslane (*Portulaca oleracea* L.), and annual grasses are controlled by ethalfluralin. Injury to cucumber from ethalfluralin differs from that of clomazone in that stunting of plants and thinning of plant stand may occur. A major factor that increases injury from ethalfluralin in cucumber is rainfall, irrigation and increased seeding depth [34, 88]. Combination of clomazone and ethalfluralin provided excellent control of annual grass and broadleaf weeds. Ref. [46] reported that applying clomazone and ethalfluralin together controlled hairy nightshade (*Solanum sarrachoides* Sendt.), redroot pigweed (*Amaranthus retroflexus* L.) and smartweed (Polygonoum persicaria L.) better than either herbicide alone. Although this herbicide combination is effective against a number of weed species, they have little to no activity on weed species such as smooth pigweed (*Amaranthus hybridus* L.), morning glory species (*Ipomoea* spp.), and yellow nut sedge (Cyperus esculentus L.) weed species which interferes with harvesting and reduce cucumber fruit quality [26].

8. Integrated weed management in cucumber

Integrated weed management is the major component of a sustainable cucumber farming. Considering the diversity of weed problem, no single method, whether physical, mechanical or chemical can provide the desired level of efficiency under all situation [19]. Hence, cucumber growers should focus on adopting integrated weed management system to widen weed control spectrum and efficiency in a sustainable, economical, and environmental manner. Integrated weed management involves coordinated use of multiple tactics for optimizing the control of all classes of weed in an ecological and economical sound manner [43]. These tactics can be direct weed control through physical (manual and mechanical tillage/land

preparation), chemical and biological means [6]. It could also be indirect control through cultural or agronomic practices such as planting pattern, fertilization timing and placement method, sowing time, row spacing, seed rate, crop cultivar type, intercropping and cover crops [7]. These methods can influence either weed density (i.e. the number of individuals per unit area) and/or weed development (biomass production and soil cover). It is always recommended to use all available options in combination to achieve better control of weeds.

9. Conclusions

Cucumber is a difficult crop to manage as it is susceptible to the attack of numerous weeds, disease pathogens, and insect pests. Weeds reduces cucumber yield and deteriorate fruit quality. Unfortunately, cucumber is not a strong competitor against weeds particularly during the early growth stage. Hence, it is necessary to control weeds to obtain increased yield and high quality fruit from cucumber. All the weed control methods have their own shortcomings and cannot be used as a stand-alone tactics to manage weeds in cucumber efficiently. Manual weed have the constraint of high cost and labor shortage, mechanical options have their own limitations because of the increase in fuel cost, and their use is not practicable within cucumber rows and on large farm sizes. Chemical control on the other hand are always expressive, and only a few herbicides are registered for weed control in cucumber. Moreover, the few available herbicides cannot control the entire weed spectrum and provide season-long weed control when used alone. No single weed control method can provide 100% control; therefore, there is a need to adopt an integrated weed management approach to control weeds in cucumber. A good tillage operation and land preparation, the use of a competitive cucumber cultivar and appropriate plant population and row spacing, application of pre-emergence herbicides, application of post-emergence herbicides particularly along crop rows with the use of spray guard are important in reducing weed density. The combination of these approaches provides effective weed control, improves fruit quality, and helps in environmental conservation. The world is now moving toward precision weed management techniques which involve remote sensing, modelling and use of robotics to control weeds. These technologies are the future of weed management in crop production and have a substantial role to play in modern cucumber production systems. Right selection of one or more of these techniques with reference to environmental, socioeconomic, and geographic conditions will provide effective weed control in cucumber.

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