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Recent Advances in Weed Management

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Abstract

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A wide range of advances in various weed management processes have taken place. Some advances are already commercialized, others are in the process of development. Vision guided machines have been developed to selectively target weeds; such as the light beam hoe, robotic hoe, computerized laser weeder and the computerized flame weeder. Super-heated water, ultra violet and infra red radiations have been implied in non-selective weed control. Advances in herbicide applications included the development of air inclusion nozzles to reduce application volume besides reducing drift. Herbicide formulation technologies are advancing towards improving herbicide efficiency with lower doses; and making formulations more water-based with little hydrocarbon solvents. Robotic sprayer which recognizes weed images selectively spray the weeds saving much of the herbicide. Searching for new genes to develop herbicide tolerant /resistant crops is underway. The human gene CYP1A1, coding for cytochrome monoxegenases, have been inserted in rice in order to metabolize foreign compounds including several herbicides. Crops stacked with foreign genes are expected to be released in the near future. Biotech maize, Smartstax™, with eight different genes coding for several pest resistant and herbicide tolerant traits is expected to be commercialized in the near future. Genes that improve crop allelopathy and/or crop competition, or genes that code for allelochemicals that will serve as templates are also being investigated.

Keywords: Weed control, herbicides formulations, allelopathy

Introduction

Weed Management is a long-term sustainable approach that uses a wide range of control options (cultural, mechanical, biological, chemical and non-conventional) rationally to reduce weed abundance below economic threshold, economic injury…). Despite the efforts to manage weeds, they continue to interfere with crop production. There is clearly a need for development to improve weed management and improve competitiveness in non-weedy species.

Advances in weed management are largely due to advances in herbicide technology. However, the growing public awareness of the unwanted side effects led to various advances in herbicide technology as well as in other alternative weed management methods, in order to improve environmental safety and enhance agricultural productivity.

Recent advances in various aspects of weed management will be discussed.

Non-chemical weed control

The major factors driving the interest in non-chemical weed control include the increasing concern about herbicides polluting ground and surface water, human health risks from exposure to herbicides, effects on the flora and fauna, development of herbicide resistant weeds and the lack of approved and effective herbicides for minor crops, the elimination of chemical weed control in "organically/ecologically grown" crops. Furthermore, the number of herbicides available in the market is rapidly declining. Major agrochemical companies have reduced their investments in new herbicides, because of the high costs for registration, besides their focus on GM herbicide-tolerant crops which are leading the development of world agriculture (11, 17).

Inter-row weeds are relatively easily controlled by mechanical means. Intra-row weeds which grow within the line of row crop plants are not affected by inter-row weeding by the non-selective tools such as, rototillers, torsion and finger weeders. Intra-row weeds, if insufficiently controlled, cause major problems, especially for organic growers. The fact that crop plants are grown in narrow row spacing and dense stands in the rows is a strong limitation for selective physical intra-row weeding. Manual intra-row weeding can be laborious; particularly in slow-growing row crops with poor weed competitiveness. However, the perspectives for selective intra-row weed control are better in row crops that have more space between individual plants. The major obstacle to the development of selective and accurate intra-row weed control is the lack of automated detection of crop plants and weeds. The crucial requirement for an automated intra-row weeder is a high level of accuracy when operating close to individual crop plants.

A- Selective Non-Chemical Weed Control

Vision guided technology

Machine vision-based automatic row guidance

After decades of research and development, row crop guidance has achieved a high level of automation and some commercial success. Many guidance-sensing technologies

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have been attempted (10, 21, 22) and few types of sensors have achieved commercial success, specifically; machine vision and global positioning systems.

1) Light beam hoe - The first example of such a machine has been commercialized in France for weeding in lettuce (23). A light beam is interrupted when it passes over the crop plants and based on this interruption a hoe is moved in and out of the crop row. The existing version requires that the crop plants are taller than the weed plants. The French company Sarl Radis (24) has introduced the intelligent weeder for lettuce.

Intelligent weeder offers more advanced ways to control weeds and leave the crop plants unharmed. One of the first commercially available intelligent weeder has a simple crop detection system based on light interception, which guides a hoe in and out of the crop row, around the crop plants. It has been commercialized, and started being sold (at present around 20 machines a year in Europe, mainly in France).

To distinguish between crop plants and weeds, the crop plants need to be distinctly taller than the latter. The working speed is limited to 3 km $h^{-}1$, because of the mechanical limitations of the intra-row hoe. Difficulties arise if the crop has a more or less open structure (e.g. onions) and the light beam is not interrupted regularly when the machine passes a crop plant.

2) Robotic Weed Control System - Robotic weeding is not yet as close to practical application, although the University of Halmstad in Sweden has a prototype working in sugar beet (http:// www2.hh.se/staff/bjorn/mech-weed) and similar developments are taking place in the Netherlands (2, 25, 27). The module for weed control includes the weeding-tool and a plant identification system. The module could be attached to a row-cultivator or applied on an agricultural robot. A key component is the development of a special designed computer vision system that is cost-effective and powerful enough for the application. This robot uses infrared cameras and an on-board computer. Upon detecting a non-crop plant a hoe is moved in and out of the crop row, leaving the crop plants untouched. The module was sufficiently fast and robust for real-time control of intra-row weed-tool performing intra-row cultivation, able to identify 99% of the crops and remove about half of the intra-row weeds.

3) Laser weeding - Another non-chemical technology that could become of interest in particularly high-value crops is laser weeding. Early research using laser to cut the stems of weed plants revealed that the energy input required was very high. Recent research targeting the apical growing point has shown that weeds can be effectively controlled with significantly less energy input (15) and in an ongoing research project the use of laser for weed control is further studied. A CO2 laser system was tested for concentrating a large amount of light energy (a photo-thermal radiation in the far infrared region) in a narrow light beam that could be directed onto individual weed plants. This thermal small spot treatment has the advantage to be potentially low energy demanding and being operationally fast. Furthermore computer vision for weed species recognition could be used to allow selective weeding methods. CO2 laser irradiation in general has big potentials for thermal weed control (9).

4) Computerized flame weeder - A computer with a camera detects the individual plants in the row and the software calculates the position of the plants. The Plant Detection algorithms can distinguish between crop and weed. The crop plant is recorded by the camera. When it is passing under the array of burners, signals are sent from the computer which causes the plasma jets adjacent to the plant to be switched off whereas other jets are kept on. This pattern of ON-and OFF jets are moving along the array with the same speed as the machine is driving forward. The result is that the weed is destroyed while the crop is spared without moving the soil. (F Poulsen ApS Engineering http://www.visionweeding.com/Video/mekanisk-vision-low.wmv)

B- Non-Selective Weed Control Technologies

1) Weed Control by Ultra Violet Light - The energy of ultra-violet light, contrary to more long-waved light, is absorbed in a thin surface layer of biological materials which are irradiated. Measurements of green leaves show that very little ultra-violet light is reflected and transmitted, so that nearly the whole energy (approx. 90%) is transformed into heat in the outermost 0.1 mm. These conditions apply to UVA-, UVB-, and UVC-light. This effective energy consumption makes it possible with a comparatively short, intense irradiation to transfer so much energy to the green leaves and damage them. The irradiation level should exceed the minimum dosage which the plant can survive without substantial damage. The method is applicable for keeping path areas clean, for control of competing plants under and between plants, and along railway tracks. The apparatus is moved over the area, where the vegetation control is to take place, at such a speed that the necessary dosage is discharged during the passage. The more intense the energy from the light source, the more quickly can the light source be moved.

Low pressure mercury vapor lamps emit a strong light with a wavelength of 254 nm in the middle of the UVC-range, where bacteria and vira are most sensitive to irradiation. A dosage of 10,000 joules per square meter stops or retards plant growth.

2) Infra-Weeder- The new Infra-Weeder uses infrared heat to kill undesired vegetation. Infra-Weeder equipment is a Swiss development. It has been used successfully in Europe for over eight years and in British Columbia by Forevergreen Landscaping and Maintenance for over three years. Infra-Weeder equipment uses a propane-fuelled ceramic heating element that develops temperatures up to 1800 degrees Fahrenheit (1000 degrees Celsius), which applies infrared radiation to weeds. Because of the high heat produced by this machine, it eliminates windborne weed seeds, bacteria, and moulds on the ground surface. In addition, the shielded heat element prevents heat from radiating upwards or sideways so vegetation can be controlled alongside desired species without harm. The most popular unit, the hand held Eliminator, runs four hours on a standard disposable propane torch cylinder.

Due to the nature of infrared heat application, a close proximity must be maintained between the heat element and the target species, therefore it is restricted to use on relatively smooth surfaces near pools, patios, and areas where children play.

3- Super heated water - Hot water is employed by the recently developed Aquacide vegetation control system.

This new technology uses a process in which water is super heated on demand under low pressure and then pumped through a heat resistant hose to an application delivery system. This super-heated water when applied to the ground surface will eradicate unwelcome vegetation. The extreme heat of the water immediately breaks down the molecular structure in the plant killing it on contact. The Aquacide can be used in many applications including the line marking of playing fields, around public areas, between asphalt and curbs, as well as growth around fencing and poles.

Herbicide Application technology

The high cost of product discovery and development is slowing the release of new herbicides so maintaining the efficacy of existing useful compounds is imperative.

Recent advances have been made through commercial development of low-rate and post emergence herbicides. These herbicides enable overall herbicide use reduction, but their efficacy and the risk of spray drift is strongly influenced by application techniques (spray volume, droplet size, and adjuvant selection), environmental conditions and the status of the crops and weeds at the time of application.

1) Reducing drift technology - Increasing the coverage while keeping volumes low, means using spray droplets that are as small as possible. Small droplets are vulnerable to drift, though, which not only takes the chemical away from the target but also creates a risk to the environment. Hydraulic nozzle was developed with the aim of improving product efficacy, and reducing volume of the carrier. It is a system which limits the number of very fine droplets produced and limits the very large droplets (19). The fluid passes through a tapered section which accelerates the flow as it passes two slots. This reduces the pressure at the final orifice and nozzles, and air is sucked in by a Venturi effect, which then combines with the fluid to create an air/fluid mixture and produce large droplets filled with air bubbles that "explode" on contact with the target to produce a similar coverage to finer sprays. Application rates as low as 50 litres/ha when applying pesticides are possible.

2) Herbicide formulations - The main emphasis in herbicide delivery is on improving operator safety and minimizing contamination. Closed transfer will be more widely used. Aside from the classical formulations: Granules, wettable powders, water dispersible granules, tablets, soluble liquids, suspension concentrates, emulsifiable concentrates, concentrated emulsions, suspoemulsions and multiple emulsions, (more than one ai), microemulsions, microcapsules, gels, low volume and ultra low volume; future formulations are likely to be water-based, with little use of hydrocarbon solvents. Many of the surfactants will be replaced by more environmentally friendly; for example: nonylphenols are suspected to have endocrine-modulating properties, and so are being phased out in favor of safer alternatives, such as alkyl polyglycosides (26).

3) Robotic spraying - Image processing, based on machine vision technology, pattern recognition techniques, knowledge-based decision theory, and robotics, enabled robots to distinguish between crop plants from weeds. The sensing unit in the main computer captures and sends to the computer an image of the plants in the crop seedline. The computer analyzes the image to determine where (if any) weeds exist. The computer activates the precision sprayer within the spray cell when it is over the appropriate weed location. The precision chemical application system opens a corresponding spray valve and applies the herbicide to individual spray cells in which weeds are present (8, 12, 13, 14).

The cell sprayer is an intelligent real-time robotic weed control system has been developed for selective spraying of in-row weeds using an environmentally sound and friendly chemical application system. The system can either spray weeds in cells of 10 X10 cm, or deposit a single droplet in cells of 1 X 1 cm. The single droplet applicator will only target weed plants, i. e. it will be possible to use a non-selective broad-spectrum herbicide like glyphosate. Thus, reducing herbicide deposition on the soil surface to a minimum; and minimizes the risk of herbicide leaching to the groundwater or surface runoff into streams and lakes (16).

4) Herbicide resistant crops - Advances in weed management were largely due to advances in herbicide technology, which has undoubtedly led to improvements in crop productivity and farm labor efficiency. For several decades, herbicides have made up more than 50% of the agricultural pesticide market.

In the 1950s, approximately 1,000 chemicals needed to be synthesized and tested to discover a new herbicide. Today the success rate for discovering new herbicidal compounds has decreased to one in one million. As discovering new herbicidal molecules became increasingly difficult, crop developers began to apply the second approach–broadening the capacity of crops to resist herbicides.

The new genetic tools allow crop developers to identify novel herbicide resistance genes that are present in nature and transfer the new genes into crop plants.

GM Technology

Since transgenic, bromoxynil-resistant cotton was introduced in 1995, planting of transgenic crops, herbicide-resistant crops (HRC) has grown substantially, revolutionizing weed management. Transgene technology has provided a potential tool for use in managing weeds more effectively and safely.

Glyphosate-resistant soybean was introduced in 1996, followed by introduction of other glyphosate-resistant crops (GRC), especially soybean, cotton, and canola. At this time, almost all of these crops are glyphosate resistant soybean, maize, cotton, or canola. Bromoxynil-resistant crops are no longer on the market and glufosinate-resistant crops have a relatively small market share.

Although the global acreage planted in these crops continues to increase, no new herbicide resistance genes and few new glyphosate-resistant crops are scheduled for introduction in the near future. Transgenes for the resistance to many herbicide classes have been patented.

Transgenes conferring herbicide resistance in major commercialized GM crops

Herbicide	Transgene(s)	Crop & Year available
Bromoxynil	Bacterial nitrilase	Cotton 1995 & canola1999 (NA)
Glufosinate	*bar* gene	Canola 1995 maize 1997 cotton 2004
Glyphosate	CP4 EPSPS CP4 EPSPS + GOX	soybean 1996, cotton 1997, sugar beet 1999 canola 1996, alfalfa 2005

Adapted from Duke (5).

At present only four transgenes are used to confer herbicide resistance:

1- the *bar* gene for glufosinate resistance
2- CP4 EPSPS- (*Agrobacterium* gene, CP4, which encodes for a highly efficient, glyphosate-resistant form of EPSPS (18).
3- GAT gene: The enzyme, glyphosate acetyltransferase (GAT), converts glyphosate into the non-toxic molecule acetylglyphosate, before glyphosate can reach and inhibit the EPSPS enzyme. The *gat* gene was derived from a naturally occurring soil bacterium (*Bacillus licheniformis*).
4- GA21, and GOX for glyphosate resistance. All of these provide target site resistance except for the GOX gene, which encodes an enzyme (glyphosate oxidase) that degrades glyphosate. GOX is used only in canola and always along with the CP4 EPSPS gene.

More genes are being investigated and could turn out to be promising. Those genes are:

1- human CYP1A1: Cytochrome P450 monooxygenases (P450s) metabolize herbicides to produce mainly non-phytotoxic metabolites. The transgenic rice plants showed broad cross-resistance towards various herbicides and metabolized them. The introduced CYP1A1 enhanced the metabolism of chlorotoluron and norflurazon
2- a single amino acid mutation in the ALS enzyme: conferred Resistance into a wide range of agronomically useful soybean varieties, which became commercially available in 1993 as STS® soybeans (Sulfonylurea tolerant soybeans).
3- Stacked products are a very important feature and future trend, which meets the multiple needs of farmers and consumers. The stacked trait products were by far the fastest growing trait group between 2007 and 2008 at 23% growth, compared with 9% for herbicide tolerance and -6% for insect resistance

From the genesis of commercialization in 1996 to 2008, herbicide tolerance has consistently been the dominant trait. In 2008, herbicide tolerance deployed in soybean, maize, canola, cotton and alfalfa occupied 63% or 79 million hectares of the global biotech area of 125 million hectares.

For the second year running in 2008, the stacked double and triple traits occupied a larger area (26.9 million hectares, or 22% of global biotech crop area) than insect resistant varieties (19.1 million hectares) at 15%.

Biotech maize with eight genes, named Smartstax™, is expected to be released in the USA in 2010 with eight different genes coding for several pest resistant and herbicide tolerant traits.

Future stacked crop products will comprise both agronomic input traits for pest resistance, tolerance to herbicides and drought plus output traits such as high omega-3 oil in soybean or enhanced pro-Vitamin A in Golden Rice.

Environmental advantages of the currently used HRCs over non-transgenic crops using chemical and cultural wm: Lower soil erosion and compaction, pesticide use, toxicities and residues in water, fuel use

Introgression of a transgene for herbicide resistance into weedy relatives of crops is unlikely to influence natural ecosystems, but the potential for introgression of other transgenes that could alter ecosystems is probably enhanced when herbicide resistance transgenes are used with such genes, as with HRCs that also have transgenes for insect resistance. So far, only crops that are highly unlikely to introgress genes into weedy relatives have both types of genes.

Progress in Allelopathy

Allelopathy has received new attention in modern research. Targeted use of the allelopathic properties of plants could lead to a reduction of the use of synthetic pesticides. Utilizing allelopathy for weed management could have the greatest impact on synthetic herbicide of any new technology. Allelopathy involves a plant's secretion of secondary metabolites into the environment that affect germination or growth of surrounding vegetation (20). The purpose of much of the allelopathy research has been to identify allelochemicals- phytotoxins- that could serve as templates for new herbicides which provide new modes of action. Besides isolating phytotoxins, allelopathy can be exploited by cultivating crops with allelopathic properties (7). The potential economic and environmental benefits may be striking if this trait is exploited in much the same way as defense mechanisms against insects or pathogens. Transgene technology could provide a powerful tool to enhance crop competition and its allelopathic traits (6). It can be anticipated that breeders will devote more attention to breeding allelopathic crops. Allelopathic crops could be cultivated between crops and used as green mulch in order to reduce weed growth thereby increasing crop competitiveness.

The outlook for transgenes in weed management

Even though transgenic HRCs have had and will continue to have a huge direct or indirect influence on weed management, recent research on utilizing transgenes have gone further than genetic modification of pesticide resistant/tolerant crops. Transgenes for improving weed management are being researched to improve biocontrol, making crops more competitive or allelopathic, as well as engineering cover crops to self destruct in response to an environmental cue.

Transgenes were utilized to improve the virulence of certain mycoherbicidal agents such as *Colletotrichum coccodes* which infects only the weed *Abutilon theophrasti* by inserting of the protein phytotoxin (Nep1)-encoding *NEP1* gene from *Fusarium* spp. was attempted (1).

Cohen *et al.* (3). inserted two genes of the indole-3-acetamide pathway into *F. oxysporum* and *F. arthrosporioides*, resulting in transformants that produced significantly more auxin than the wild types. The *F. oxysporum* transformant with both genes and *F. arthrosporioides* with only the gene encoding tryptophan-2-monooxygenase were more effective biocontrol agents on the parasitic weed *Orobanche aegyptiaca* than the respective wild types (3, 4).

Transgenes were also exploited to make crops more competitive by making crops grow faster, more tolerant to stress or pests, or allelopathic. Enhancing the allelopathic potential of *Sorghum* spp. through enhancing gene expression of genes encoding the enzymes of the sorgoleone pathway was attempted (6).

Transgenes were also exploited to engineer winter cover crops in temperate climates to self destruct prior to planting summer crops in response to an environmental factor such as heat wave or a photoperiodic response. This will reduce the need for herbicidal treatment.

Recently, three strategies for transgene utilization have been developed that have the potential to change this. These are the improvement of weed-specific biocontrol agents, enhancement of crop competition or allelopathic traits, and production of cover crops that will self-destruct near the time of planting. Failsafe risk mitigation technologies are needed for most of these strategies.

الملخص

أبو رميلة، بركات. 2009. التطورات الحديثة في إدارة مكافحة الأعشاب. مجلة وقاية النبات العربية، 27: 245–250.

شملت التطورات الحديثة في إدارة مكافحة الأعشاب عدة مجالات منها ما أصبح متداولا، وأخرى ما زالت تحت التطوير. حيث تم تطوير آلات فيها حسّاسات للرؤيا من أجل تمييز شكل الأعشاب ومكافحتها انتقائيا دون الإضرار بالمحصول مثل آلة العزق التي تستخدم الشعاع الضوئي، أو آلة العزق الآلية وآلات تستخدم شعاع الليزر أو اللهب. كما تم تطوير آلات تستخدم المياه المسخنة فوق العادة (Super-heated water) وآلات تستخدم الأشعة فوق البنفسجية أو الأشعة فوق الحمراء من أجل إزالة النباتات دون تمييز. أما في مجال تكنولوجيا الرش، فقد تم تطوير بخاخات رش تدخل الهواء في قطرات محلول الرش بحيث يتم رشها كفقاقيع (Air-inclusion Nozzle) من أجل تغطية مساحات كبيرة بأحجام رش قليلة دون إحداث رذاذ متطاير. كما تم تطوير تجهيزات مبيدات جديدة تزيد من فعالية المبيد بجرعات أقل وتحتوي على مستحلبات أو مواد مضافة أخرى أكثر أماناً للبيئة والصحة العامة ولا تحتوي على كثير من المذيبات الهيدروكربونية. وقد تم تطوير آلات رش روبوتية (Robot sprayer) تميز الأعشاب وترشها دون رش نباتات المحصول. ولا يزال البحث عن مورثات/جينات جديدة لتطوير المحاصيل لتحمل مبيدات الأعشاب أو الحشرات أو الأمراض جارياً. وقد تم حديثاً إدخال مورث/جين آدمي ينتج إنزيمات سيتوكرومية أحادية الأكسدة (CYP1A1) في الأرز لتكسير المواد الغريبة الداخلة في النبات والتي منها مبيدات الأعشاب. وأصبح ادخال أكثر من جين لتطوير محاصيل تحمل أكثر من صفة مقاومة للاجهادات المختلفة الإتجاه الحديث في البحث. وسوف يتم قريبا تداول ذرة صفراء مطورة تحتوي على ثمانية مورثات/جينات لمقاومة مبيدات الأعشاب وآفات وإجهادات مختلفة تحت الاسم Smartstax™. ولا يزال البحث جاريا للتعرف على الجينات التي تحسن من مقدرة المحاصيل التنافسية و الاليلوباثية.

كلمات مفتاحية: مكافحة الأعشاب، الأليلوباثي، مركبات مبيدات الأعشاب

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