Proceedings of the 7th Congress on Plant Protection

Доклады 7-ого Конгресса по защите растений

Plant Protection Society of Serbia
Общество по защите растений Сербии

International Organization for Biological Control
-East Palearctic Regional Section (IOBC-EPRS)
-West Palearctic Regional Section (IOBC-WPRS)

Международная организация по биологической борьбе
- Восточно палеарктическая региональная секция (МОББ-ВПРС)
- Западно палеарктическая региональная секция (МОББ-ЗПРС)

Editors/Редакторы

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„Integrated Plant Protection – a Knowledge-Based Step towards Sustainable Agriculture, Forestry and Landscape Architecture“

(November 24-28, 2014, Zlatibor, Serbia)

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„Интегрированная защита растений - научно обоснованный шаг к устойчивому развитию сельского хозяйства, лесоводства и пейзажной архитектуры“

(24-28 ноября 2014 года, Златибор, Сербия)

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on the occasion of the 60th anniversary of the PPSS
по поводу 60-летия ОЗРС

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PREFACE

The Plant Protection Society of Serbia (PPSS) and two regional sections of the International Organization for Biological and Integrated Control (IOBC-EPRS and IOBC-WPRS), on the occasion of the 60th anniversary of the PPSS organized VII Congress on Plant Protection with a motto: *"Integrated Plant Protection – a Knowledge-Based Step towards Sustainable Agriculture, Forestry and Landscape Architecture"* (November 24-28, 2014, Zlatibor, Serbia). The Congress enabled exchange of up-to-date scientific and technical information on plant protection in Agriculture, Forestry and Landscaping among researchers, teachers, experts in extension and public services and the business community, and promoted international cooperation. The Congress focused on basic knowledge and management practices established in plant protection, as well as on the development of alternative and innovative approaches. In addition, biological control as an important tool for the control of the harmful organisms with a minimal risk for ecosystems was discussed. A total of 209 contributions was presented - 8 keynote presentations, 28 oral presentations and 173 poster presentations - prepared by 467 authors from 26 countries. The Congress Proceedings comprise 65 contributions - 5 keynote presentations and 60 oral and poster presentations in six sessions, prepared by the authors from 18 countries (Algeria, Austria, Bosnia-Herzegovina, France, Georgia, Hungary, Italy, Kazakhstan, Montenegro, Poland, Russia, Rwanda, Serbia, Slovenia, Switzerland, Turkey, Uganda, USA). All contributions were reviewed by members of the Scientific Committee and other reviewers selected and invited by the editors of this publication.

Belgrade, November 2015 Editors

ПРЕДИСЛОВИЕ

Общество по защите растений Сербии (ОЗРС), Международная организация по биологической борьбе с вредными животными и растениями - Восточно палеарктическая региональная секция (МОББ-ВПРС) и Международная организациая по биологической борьбе и интегрированной системе защиты растений - Западно-палеарктическая региональная секция (МОББ-ЗПРС), по поводу 60-летия ОЗРС организировали VII Конгресс по защите растений, под девизом: *"Интегрированная защита растений - научно обоснованный шаг к устойчивому развитию сельского хозяйства, лесоводства и пейзажной архитектуры"* (24-28 ноября 2014 года, Златибор, Сербия). Цель Конгресса была обеспечение континуитета взаимообмена научно-техническими информациями, отвечающими современным требованиям защиты растений в сельском хозяйстве, лесоводстве и пейзажной архитектуре, которые представляют интерес для ученых, исследователей, преподавателей, экспертов-советников в области сельского хозяйства, лесоводства и пейзажной архитектуры, специалистов государственных и коммунальных служб, деловых кругов и средств массовой информации. Целью Конгресса является и продолжение содействия развитию и популяризации международного сотрудничества. Конгресс был концентрирован на основные знания и практический менаджмент в защите растений, а также на развитие алтернативних и новых подходов. Биологическая защита каторая представляет значительный способ для безопасной борьбы с вредними организмими была тоже рассмотривана. На конгрессе представлено 209 презентаций - 8 докладов по приглашению, 28 устных и 173 постер презентаций - которые подготовило 467 авторов из 26 стран. Сборник имеет 65 докладов - 5 докладов по приглашению и 60 устных и постер презентаций, распределенных в шести секциях. Авторы докладов приехали из 18 стран (Алжир, Австрия, Босния-Герцеговина, Франция, Грузия, Венгрия, Италия, Казахстан, Черногория, Польша, Россия, Руанда, Сербия, Словения, Швейцария, Турция, Уганда, США). Рецензенты всех опубликованных докладов в сборнике – члены Научного совета и другие рецензенты, выбранные редакторам этого издания.

Белград, Ноября 2015 — Редакторы

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INTEGRATED WEED MANAGEMENT IN FIELD CROPS: SUSTAINABILITY AND PRACTICAL IMPLEMENTATION

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ABSTRACT

Integrated Weed Management (IWM) is a sustainable approach to the management of weeds by combining all available weed control techniques, including preventative measures, monitoring, crop rotations, tillage, crop competition, mechanical and physical control, herbicide rotation, herbicide mixtures, biological control, nutrition, irrigation, burning, etc. in a way that minimizes economic, health, and environmental risks. The first step in IWM program is to monitor the fields for signs of weed infestation or potential weed problems. Proper weed management involves a thorough survey of each field after crop harvest to identify major weed species in the field. When an annual crop (maize, sugar beet, soybean, wheat, etc.) is to be grown in the field in the following year, this information is used to assess the importance of each weed species and to select the appropriate management strategy to be used for the coming crop. In annual crops, fields are also monitored after the crop has emerged, to assess the effectiveness of the selected management alternative and whether additional management measures are needed. For planting perennial field crops, such as alfalfa, an assessment of weed species composition is conducted after harvest of the previous crop, to determine the appropriate management alternative to be used during the establishment. In an established crop, fields are monitored to determine the need for additional measures to manage annual, biennial and perennial weed species.

Cultural practices in the control of weeds include anything which makes the crops more competitive against them: proper seedbed preparation, planting time, fertilization, crop rotation, row spacing, seeding rate, and variety selection. Mechanical weed control includes the use of pre-plant tillage such as ploughing, disking, and field cultivating. These primary and secondary tillage systems can help reduce the rate and spread of certain perennial weeds such as *Agropyrum repens, Sorghum halepense, Taraxacum officinale*, etc. After planting operations such as rotary hoeing, row cultivating, flaming and hand hoeing can help reduce the dependence on herbicides. Finally, herbicides should provide a convenient, economical and effective way for the management of weeds. They allow the fields to be planted with less tillage, allow earlier planting dates, etc. Herbicides may not be a necessity on some farms (organic agriculture), but without the use of chemical weed control, preventive, mechanical, physical and cultural control measures become that much more important. When choosing a herbicide program, the decision should be based on potential weed problems, crop and herbicide rotation, injury potential, tillage system and available application equipment, soil texture and organic matter, potential environmental hazards, and cost. Herbicide rotation is an important management consideration. Rotating herbicides reduces the risk of developing herbicide-resistant weeds. Other tactics that help prevent the development of resistant weeds include: using herbicide mixtures that contain more than one herbicide class;

using shorter soil residual materials, including non-chemical control measures; avoiding spreading resistant weed seed with machinery or in manure; and helping destroy weed-seed-infested forage by ensiling.

This higher level of complexity partly explains why IWM has not received the same attention as integrated management of other pests. Adding to the complexity is that most non-chemical tools are not as effective as herbicides, i.e. they cannot be considered as stand-alone methods but have to be combined with other methods in a systematic way to provide sustainable and reliable weed control. Finally, some non-chemical weed management options incur an additional cost that needs to be balanced against the potential long term benefits of more sustainable IWM strategies.

Key words: integrated weed management, sustainability, implementation

INTRODUCTION

Weeds are troublesome in many ways, because they reduce crop yield by robbing them of light, water, soil nutrients and space (Ghersa et al., 2000). Also, weeds can produce allelopathic substances that are toxic to crop plants (Jabran et al., 2015). Weeds often serve as hosts for crop diseases and optimal places for diseases to overwinter. Some weeds, such as *Agrostemma githago*, *Avena fatua, Cuscuta campestris* and many others also reduce the crop quality. Because of this and the current practice, the future of sustainable weed control must be based on the implementation of the principles of Integrated Weed Management (IWM). Consequently, IWM strategies are focused on:

- Limiting weed establishment in the crop from the soil seed bank or subterranean vegetative organs such as roots, rhizomes, bulbs, tuber-bulbs, etc. (Clements et al., 1996);
- Limiting competition for resources such as light, nutrients and water by removing weeds or manipulating the weed flora to reduce their competitive impact (Röhrig & Stützel, 2001; Chauhan & Abugho, 2013);
- Limiting the return of seeds or their vegetative organs to the soil seed/vegetative organ bank (Benech-Arnold et al., 2000).

An IWM strategy attempts to achieve one or more of these goals and this framework shoud assess the sustainability and resilience of IWM strategies. Therefore, IWM is a sustainable approach to managing weeds by combining all available weed control techniques, including preventative measures, monitoring, crop rotations, tillage, crop competition, mechanical and physical control, herbicide rotation, herbicide mixtures, biological control, nutrition, irrigation, burning, etc. in a way that minimizes economic, health, and environmental risks (Swanton & Murphy, 1996; Vrbničanin et al., 2006; Wilson et al., 2009; Peshin & Pimentel, 2014). Because the available techniques typically have lower individual efficacy than herbicides, IWM requires the combining of different measures. It is unlikely that a single control measure on its own will be effective in the long run. The concept of IWM is to maintain balanced weed flora and to reduce the reliance of cropping systems on herbicides, by adopting all available tools for the decrease of weed pressure and competition. Consequently, IWM has been referred to as "many little hammers" in the modern cropping practices.

Basic Principles and Reasons for the Implementation of IWM

The concept of IWM has been proposed as a component of Integrated Pest Management (IPM), a crop production paradigm in-between conventional agriculture and organic farming (El Titi, 1992). The objectives of IWM-based systems are to reduce the reliance on herbicides by adopting agronomic measures: (1) reduction of weed seed banks in the soil (2) decrease of the density of weeds emerging in crops, (3) reduction of their relative competitive ability, and (4) control of emerged weeds using non-chemical techniques (Pardo et al., 2010). Furthermore, in the modern agricultural practices there are more reasons why the IWM system is the most appropriate long-term strategy for weed control, such as: (1) the increasing concern for the effects of herbicides on human health and environment, (2) the development of herbicide resistant weeds, (3) weed shifts, (4) invasive weeds and climate change, (5) the slow development of new herbicides, etc.

Finally, in the past two decades weed management has become a key issue for European agricultural practices due to following reasons: (1) frequent herbicide treatments in most crops throughout Europe, except, of course, in organic farming, (2) herbicides are the pesticide residues most frequently found when analysing the quality of surface and ground-waters, (3) the development of weed populations resistant to the most frequently used herbicides has become a real threat to the sustainability of current chemical weed control strategies, (4) the increase in cost of chemical crop protection, due to the withdrawal of several old and cheaper herbicides (Ramesh, 2015). Therefore, these are key points for implementing innovative strategies which focus on lower pesticide inputs and combine all available weed control techniques within the IWM concept.

Networking Research and the Main Factors for Successful IWM

The development of an IWM system must take all aspects of the cropping system into consideration. Generally, each cultural practice influences the competitive ability of both the crop and the weed community, leading to a multitude of complex interactions. However, efforts must be made to work within the existing production practice to ensure a greater likelihood of acceptance by the cropping community. Thus, it is important to change the existing system in a progressive manner. This progression must be reflected in the research strategy. According to Swanton & Weise (1991) this would allow for the transfer of specific components through education and extension, while research continues to refine and further develop the system (Figure 1).

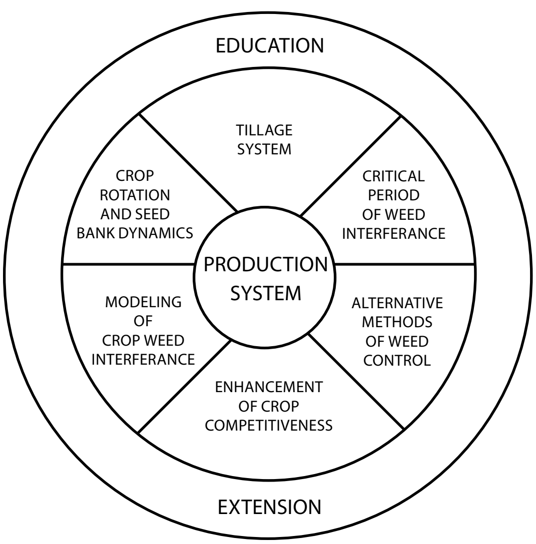

Figure 1. Research strategy for the development of an integrated weed management system (Swanton & Weise, 1991)

The different components of IWM, such as crop selection, crop husbandry, plant nutrition, crop protection, farm hygiene, and the site-specific conditions, all are factors which influence the successful adoption of the basic IWM concept. Farmers' field activities, directly or indirectly, influence weed growth in almost every phase during the vegetation period. According to Zoschke & Quadranti (2002) major factors affecting weeds and consequently weed management efficiency are summarized in Figure 2. Crop selection, crop husbandry, plant nutrition, crop protection, and farm hygiene are all factors which, in one way or another, have been demonstrated to affect the germination and development of weeds, as well as weed population dynamics. Additionally, the site specific conditions ('location') are of major importance (Zoschke & Quadranti, 2002).

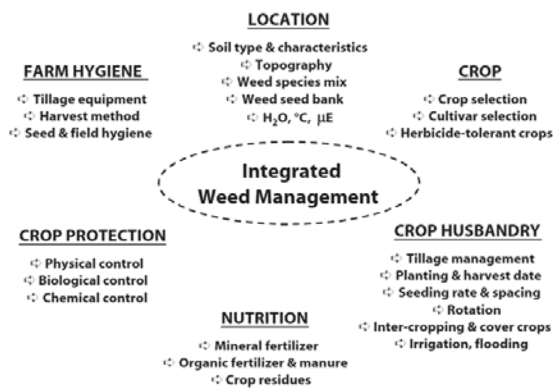

Figure 2. The main factors affecting weed management efficiency (Zoschke & Quadranti, 2002)

Preventive Practices

Generally, the best start of any weed management program is to reduce the potential for weed seeds introduction into the field. Preventive practices may include many activities such as: (1) avoiding introduction of new weed species and where possible preventing the introduction of endemic weed seeds in inputs such as manure or compost, (2) control of weeds in the field, before they have the chance to set seeds, (3) control of weeds in the field margins to prevent the entry of weed seeds into the field, (4) planting of certified crop seeds, (5) controlling volunteer weeds and patches of new species or herbicide-resistant weeds, (6) cleaning equipment (especially tarping grain trucks), (7) using well-composted manure, and etc. (Knezevic, 2014).

Weed Monitoring

The first step in an IWM program is to monitor fields for signs of weed infestation or potential weed problems. Proper weed management involves a thorough survey of each field after crop harvest to identify major weed species in the field. When an annual crop (maize, sugar beet, soybean, sunflower, wheat, barley, etc.) is to be grown in the field the following year, this information is used to assess the importance of each weed species and to select the appropriate management strategy to be used for the coming crop. In annual crops, fields are also monitored after the crop has emerged to assess the effectiveness of the selected management alternative and whether additional management measures are needed. For planting perennial field crops, such as alfalfa, an assessment of weed species composition is conducted after harvest of the previous crop, to determine the appropriate management alternative to be used during the establishment. In an established crop, fields are monitored to determine the need for additional measures to manage annual, biennial and perennial weed species.

Weed Seed Bank Management

A soil seed bank includes all viable seeds and vegetative propagules present on and in the soil which might have originated from the recent seed rain of previous years (Shrestha et al., 2002). Therefore, in principle, weed seed bank management can be integrated into a strategy for the control of weed aboveground infestations. Weed species abundance and diversity determine the structure of the weed seed bank in arable lands (Bellinder et al., 2004). Soil seed bank populations are significantly influenced by both crop rotation and tillage type (Ball, 1992; Blackshaw et al., 2001). However, crop rotation is more influential than any other practice (Cardina et al., 2002). Crop rotation creates a higher possibility for weed mortality, when compared to monoculture (Martin & Felton, 1993). Also, variation in crop sequences can increase weed emergence, establishment and seed production (Dorado et al., 1999). Understanding the influence of crop rotations and their companion impacts on weed seed bank provides helpful information to improve decision making systems (Hosseini et al., 2014). Additionally, for weed seed bank management, agricultural engineers from the University of South Australia in collaboration with AHRI (Australian Herbicide Resistance Initiative) are applying the "Harrington Seed Destructor" known as the Integrated Weed Destructor (IWD). It has been widely acknowledged by many in the agricultural industry that weed seed destruction at harvest is necessary as a key non-herbicide weed control tool to manage herbicide resistant weeds (http://ahri.uwa.edu.au).

Innovation in Mechanical and Physical Weed Management

As a consequence of the EU pesticide policy, in addition to national pesticide action plans, many herbicides have been withdrawn from the EU market (Jensen et al., 2014). Non-chemical methods will be necessary to fill the gaps where herbicides are no longer available or where those approved do not cover the spectrum of weed species causing problems. When compared with herbicides, mechanical and physical weeding practices such as weed harrowing, hoeing, disking, brush weeding, torsion and finger weeding or flaming are usually less effective, both in the short and long term (Melander et al., 2015). But, inter-row cultivation is commonly employed in row crops, in both conventional and organic farming (Malidza et al., 2009). Also, primary and secondary tillage can help reduce the rate and spread of certain perennial weed species such as *Agropyrum repens, Sorghum halepense, Taraxacum officinale*, etc. (Conn, 1987; Carter et al., 2002).

In the past decade, especially in organic farming, flame weeding has shown to be particularly promising. The advantages of flame weeding are that it leaves no chemical residue in the soil and water and does not disturb the soil, however, its disadvantage is its high consumption of costly fossil fuels (Ascard, 1998; Datta & Knezevic, 2013). Flame weeding is an acceptable weed control option in both organic and conventional production systems. Flaming is used mostly as one part in a weed control process that involves other methods that are usually applied later (Knezevic et al., 2013). Pre-emergence flaming, followed by post-emergence brush weeding have been found to be particularly promising. Also, hoeing close to the row may be as good as brush weeding in some situations (Melander & Harvig, 1997).

Crop competitiveness

Field studies showed that enhancing crop competitiveness by planting competitive varieties at relatively high seeding rates and through strategic fertilizer placement including sub-surface banded or point-injected nitrogen can reduce the impact of weeds on the crop yield and the amount of weed seed entering the soil seed bank (O'Donovan et al., 2007; Vrbničanin et al., 2012). Enhancing crop competitiveness also improves herbicide performance, especially when herbicides are applied at reduced doses. Crops differ in their competitiveness with weeds, based on their emergence, leaf-area expansion, light interception, canopy architecture, leaf-angle, shape and competitiveness (Isaac et al., 2013). Within a crop species, cultivars may vary in their competitiveness. While the improved varieties may be high yielding, the traditional varieties exhibit multiple adaptations, competitive ability against weeds and require less agricultural input. The use of competitive crops to discourage weeds is an important IWM strategy. To maximise the crop production, by minimising the impact of weeds, replacement series and additional series designs have been recommended for intercrop, cover crop and green manure selection (Maxwell & Donovan, 2007).

Cover crops

Cover crops can be very effective in suppressing weeds. Cover crops may be sown into extant crops, or the crop residue left after harvest, to reduce the time when weeds grow without competition from the crops (Swanton & Murphy, 1996). A cover crops' biomass and canopy helps it compete with weeds (Liebman & Davis, 2000). There are at least two major types of cover crops that can be used for weed control: (1) off-season cover crops and (2) smother crops (a cover crop grown during parts or all of the cropping season) (Buhler, 20002). When using off-season cover crops, the goal is to produce sufficient plant residue to create an unfavorable environment for weed seed germination and establishment. When using a smother crop, the goal is to displace weeds from the harvested crop through resource competition. Furthermore, cover crops may reduce soil erosion and improve soil structure and nutrient cycling (Wagner-Riddle et al., 1994).

Site-Specific Weed Management

Information and technology based agricultural management system are used to identify, analyse, and manage spatial and temporal variability within the fields, for optimum profitability, sustainability, and environmental protection (Robert et al., 1994). Although weeds are not uniformly distributed across the fields, most weed control practices are applied uniformly. The uniform application of herbicides over non-uniform weed populations was identified as an important source of inefficiency in weed management (Cardina et al., 1997). Site-specific weed management may result in reductions of herbicide quantities used and ecological and economic benefits.

Major limitations with mechanical weeding include limited weed control in crop rows at early, vulnerable crop stages, weather-dependent effectiveness, and difficulties in handling crop residues. Precise steering and depth control, improved seedbed friability and lighter tractors or controlled traffic could bring considerable improvements. To expose weed seeds to predators, position them for fatal germination, viability loss or low emergence may require completely different soil displacement patterns than those of current implements and systems. Controlled traffic and precise strip tillage offer good opportunities for implementing these weed management strategies in minimum-tillage systems (Kurstjens, 2007).

GPS technology and GIS software methods are widely available commercially and have been used by weed scientists in the manual development of geo-referenced maps of weed distributions in agricultural fields. When integrated with machine vision, the weed sensing technology allows for the automatisation of this valuable management tool. Despite these challenges, there have been few completely robotic weed control systems demonstrated in the agricultural fields, under a limited range of conditions. These systems demonstrate the promise of robotic weed control technology for reducing the hand labor or pesticide application requirements of existing weed control methods (Slaughter et al., 2008). Commercial equipment is already available for non-selective patch spraying, such as the Crop Scouting Drones Miniature UAV helicopter, equipped with a camera and GPS navigation system for low-altitude aerial imaging (http://www. mikrokopter.de).

Biological control

Biological control of weeds (BCW) is defined as the action of parasites, predators, or pathogens in maintaining another organisms' population at a lower average density than the one which would occur in their absence (McFadyen, 1998). Biological control is properly employed as one of many weed management practices. It is likely that biological control of weeds will become more important than other control techniques, but it will never be the solution for all weed problems in intensive crop production. Some of the benefits of BCW are that it is: reasonably permanent, self-perpetuating, there are no additional inputs required once the agent has established itself successfully, there are no harmful side effects, the "attack" is limited to the target weed and few of its close relatives, the risks are known and evaluated before the release, control is often dependent on the host density, the spread to suitable host habitats is self-dispersing, the costs are non-renewing, it brings high benefits (Suckling, 2013). However, BCW also has some risks such as: slow weed control, there is no guarantee of results, the establishment may fail for many reasons, there may be unknown ecological effects, some risks may not be known and cannot be evaluated in advance, it does not work well in short-term cropping cycles, the restriction of spread from the area of its initial dispersal is impossible, the initial cost, in terms of time, money and personnel needed, can be very high and weed eradication is not possible (Sheppard et al., 2003; Simberloff, 2011). The commercial applications of biological control have mainly been developed in fruit and protected cropping systems. The available systems are currently too costly and not effective enough for their use in arable crops (row crops, small grain crops, legumes, etc.). However, the establishment of wildlife features, such as beetle banks and conservation headlands, may supply organisms which would feed on the field weed species. The first classical biological control agent release against an invasive alien plant in Europe was the release of *Aphalara itadori*. Like its host, *Fallopia japonica*, *A. itadori* originates from Japan, where it is one of more than 180 insects that feed on this plant. Therefore, *A. itadori* has potentially become the first classical biological weed control agent for the European Union (Djeddour & Shaw, 2010).

Herbicide-Resistant Weeds

Repeated exposure of a weed population to any herbicide in isolation may have two effects: (1) weed species that are not controlled by the herbicide will dominate the population (species shift), and (2) the pressure will be exerted on the population to select any resistant individuals that may be present (herbicide resistance). The development of both the species shift and herbicide resistance can be effectively managed by the practice of IWM (Beckie, 2014). The implementation of IWM to avoid both of these problems considers two key aspects: (1) diversifying weed management practices and using multiple herbicide mechanisms of action (MOAs), and (2) educating the farmers about MOAs and making them aware that the discovery of new herbicide chemicals is rare, and that the indiscriminate herbicide use leads to the rapid evolution of herbicide-resistant weeds, which in turn may result in the loss of herbicide options for all weeds. Therefore, herbicide resistance management encompasses the following practices (Friesen et al., 2000; Bozic et al., 2015):

- Use of herbicide mixtures, sequences of herbicides and the rotation of herbicides that have different MOAs;
- Use of full recommended rates of herbicides, applied at the right time;
- Use of short residual herbicides whenever possible. Use of long term residual herbicides wisely and not continuously on the same field;
- Practicing crop rotations to keep any one weed species from dominating;
- Utilising tillage where applicable as a component of the weed management;
- Utilising cultural practices, reducing row spacing, maximising the crop competitiveness;
- Scouting the fields and monitoring them for resistance and weed shifts; and
- Practicing good sanitation practices to prevent the movement of weed seeds with the soil, machinery, crop residue, etc.

IWM in Herbicide-Tolerant Crops

Herbicide tolerant crops (HTC) have been developed through conventional breeding techniques (conventional herbicide tolerant crops (Miller & Al-Khatib, 2004; Bozic et al., 2012) and through gene transformation (biotech-derived herbicide tolerant crops (Reddy, 2001)). Implementing IWM for HTC is equally applicable for all types of farming systems, both in the conventional as well as in the conventional vs. biotech-derived herbicide tolerant crops. HTC currently provides many weed control benefits, such as: (1) simplified weed control, (2) better weed control, (3) reduced crop injury, (4) lower weed control costs, (5) fewer herbicide carryover problems, (6) new herbicide modes of action for the control of resistant weeds, (7) environmental benefits, (8) enabling zero tillage systems and (9) reduced fuel costs (Heap, 2012; Elezovic et al., 2012; Knezevic et al., 2013). Bearing in mind the above-mentioned benefits of growing HTC, farmers must practice diversified IWM in HTC.

Future Research Opportunities on IWM

Further research on IWM must continue to further advance the principles of weed science. Every effort must be made to move from a descriptive to a predictive science, in order to overcome the acceptance barriers. Opportunities will arise to further explore the ways to reduce management risks and the environmental impact of our agricultural production systems. Also, the agro-industry, farmers, and governments must view IWM as an important component of herbicide and environmental stewardship. Additionally, IWM is a flexible approach that is not based on prescription, however, weed scientists must bear in mind the fact that increasing farm sizes demands simple, effective and flexible methods for weed management (Buhler, 2002). A key role for weed scientists is, therefore, to integrate the complexities of IWM into user-friendly decision support systems to meet these demands.

Ultimately, future decision support systems should incorporate different weed management strategies, past informations from the field, and real-time environmental conditions to recommend the most appropriate weed management strategies (Swanton et al., 2008). Such systems would help satisfy the growing needs for simple, effective and flexible weed management, and at the same time promote IWM practices.

CONCLUSION

This higher level of complexity partly explains why IWM has not received the same attention as integrated management of other pests. Adding to the complexity is the fact that most non-chemical tools are not as effective as herbicides, i.e. they cannot be considered as stand-alone methods, but has to be combined with other methods in a systematic way to provide sustainable and reliable weed control ("many little hammers"). Finally, the challenge for weed scientists is to develop innovative, economical IWM systems that can be integrated into current and future cropping systems to bring a more diverse and integrated approach to weed management. Because of the diversity and flexibility of weed communities, weed management needs to be a continuous process.

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